Master's thesis

NTNU
Norwegian University of Science and Technology
Faculty of Information Technology and Electrical Engineering
Department of Computer Science

Dennis Jianbin Liang

eCim - An evaluation of a complex system simulation model of energy consumption within an urban context

Master's thesis in Computer Science
Supervisor: Sobah Abbas Petersen
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TDT4900 - Master Thesis in Computer Science

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Abstract

This thesis sets out to identify the applications and the benefits of complex system modeling by simulating an urban context. The overall goal is to create an evaluable simulation model that identified stakeholders could evaluate based on how it could benefit them. A literature review consisting of relevant topics related to modeling approaches, the city as a complex system, and data to build models has been performed to overview the topics central to the thesis. The code implementation builds on the existing model *CitySim*, which simulates traffic and movement of people by utilizing agent-based modeling. The thesis defines and conducts three experiments to demonstrate example applications for the complex system model. Identified stakeholders then evaluate the model, providing feedback for the model and its areas of use. The main contribution of the thesis consists of modifying an existing framework to present an experiment that affects an urban system using complex system theory and agent-based modeling in addition to collect feedback from relevant stakeholders. As a result, the simulation model was proved beneficial for the stakeholder group consisting of architects and urban planners. The simulation model in this thesis is called eCim, and the source code can be found here.

Sammendrag

Denne oppgaven går ut på å identifisere bruksområdene og fordelene med kompleks systemmodellering ved å simulere en bysammenheng. Det overordnede målet er å lage en evaluerbar simuleringsmodell som identifiserte interessenter kan evaluere basert på hvordan modellen kan være fordelaktig for dem. Et litteraturstudie bestående av relevante emner til modelleringsmetoder, byen som et komplekst system, og data for å bygge modeller har blitt gjennomført for å gi en oversikt over temaene som står sentralt til oppgaven. Kodeimplementasjonen bygger på den eksisterende modellen *CitySim*, som simulerer trafikk og bevegelse av mennesker ved hjelp av agentbasert modellering. Oppgaven definerer og gjennomfører tre eksperimenter for å demonstrere eksempelbruk av modellen. Deretter evaluerer identifiserte interessenter modellen, og gir tilbakemelding til modellen og dens bruksområder. Oppgavens hovedbidrag består av å modifisere et eksisterende rammeverk for å presentere et eksperiment som påvirker en bysammenheng ved bruk av kompleks systemteori og agentbasert modellering, samt samle tilbakemelding fra relevante interessenter. Resultatet var at modellen viste seg å være gunstig for interessentene bestående av arkitekter og byplanleggere. Simuleringsmodellen i oppgaven heter eCim, og kildekoden finnes her.

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Abbreviations

RQ	Research Question
CAS	Complex Adaptive System
ABM	Agent-Based Modeling
MAS	Multi-Agent System
GUI	Graphical User Interface
GIS	Geographical Information System
TAM	Technology Acceptance Model
FIFO	First in first out

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Chapter 1

Introduction

This chapter will focus on definitions and the background of the thesis. The contributors will also be introduced, alongside the research questions, the project's research goals, and the overall structure for this paper.

1.1 Background and Motivation

Discovered in the specialization project conducted in the fall of 2020, more and more of the world's population are moving to the cities and their respective suburbs [7][8]. As a result, the most significant cities get more and more crammed with people and the demand for solutions regarding urban planning increases. Correspondingly, energy demand across the city and its suburbs increases as a consequence of the increased population.

With the people living in the city context in mind, an overall energy demand pattern can be observed [9]. A dense concentration of people in office and industrial areas during work hours and equivalently, for off-work hours in residential areas can be seen [10]. Problems include the sudden increase of energy demand within a geographically confined area [9]. This poses one of the more significant challenges for the electric industry [11], as the need for designing structures that can handle the peaks is costly and ineffective during less intensive hours.

Significant responsible actors for energy consumption are daily commuters [12][13] through increased emissions, and overall energy consumption from industrial buildings, including office spaces [14]. Why is it that people working in the city need to travel a significant distance to work within a confined area? How would it look like if they did not have to travel to work? What happens overall if workers were evenly distributed at the workspaces in the urban context? What would then happen to the emission and energy consumption as a result of the change?

Due to a global pandemic that happened in 2020, it became evident that physical presence at workplaces is not necessary nor required for many professions. Impacts of the pandemic threw industries into involuntary experiments with working from home, as governments worldwide required restricted movements and general lock-down of society. The results have shown that occupational mobility is functioning [15]. A study done by Dubey et al. [16] analyzing the sentiments towards a culture of working from home, with a sample size of 100 000 participants, shows that about 73% had a positive sentiment towards this kind of arrangement. The study indicates that people, to some degree, enjoy working from home and are able to work remotely and more freely, both in terms of time and space, being holistically more distributed through urban space. A permanent scheme with occupational mobility could result in a permanent change within a city, leading to opportunities for change in the physical structure or the physical environment. An example is a parking space that is no longer needed, being utilized for a park or a new building. However, such permanent changes usually contain much risk, are very costly, and take considerable time to conduct. A tool to simulate such change and the consequences could be highly beneficial and valuable for planners, city counsels, or whatever governing body to get a hold of what the future could potentially bring.

Inspired by the preliminary talks with two people from Trondheim Municipality during the pre-study, in addition to the author of this thesis' own experience from a bachelor's degree in Architecture, this master's thesis will attempt to discover how Complex System theory and Agent-Based Modeling could benefit potential stakeholders.

Considering the city as an urban Complex Adaptive System, how will behavioral changes of individual citizens affect the overall picture of a city context? What kind of emergent behavior that affects the bigger picture resulting from this change will be discovered? How can such data be valuable? The main focal point in this thesis would be how complex system simulation models can bring value to potential stakeholders.

1.2 Research Questions and Objectives

With roots to the background and motivation, the two overall research questions for the thesis would be:

Question 1: How can complex system models be used as a tool to understand energy distribution within an urban context?

Sub-Question 1.1: Why would such a case be suited to model as a complex system?

Question 2: How could a complex system model of an urban context be beneficial for potential end-users?

Research question 1 with its sub-question is to be answered through the conducted literature review. In addition, the implementation, mainly the models and simulations created, will be a part of answering the research question. Finally, an expert evaluation conducted with identified potential stakeholders will contribute to answering research question 2.

The goals which the author of the thesis wishes to achieve for the thesis are the following:

Goal A: To achieve an overview of complex system model theory and agent-based model theory to be able model urban systems such as cities.

Goal B: To define a conceptual model for simulating and analyzing the activities within the defined context, describing the actors involved, the environments they reside in, and how the environment is affected.

Goal C: To identify needs and specific valuable aspects of a model, based on feedback from stakeholders

1.3 Contribution

This master thesis contributes to the body of literature by modifying an existing model framework to fit its purpose of presenting an experiment that affects an urban system, utilizing complex system theory and agent-based modeling. Furthermore, the thesis evaluates the modified simulation model against a group of identified stakeholders, uncovering the benefits of the complex system model in the stakeholders' field of work based on their feedback.

1.3.1 Pre-study: Summary of specialization project

The specialization project conducted in the fall of 2020 served as a pre-study for this master's thesis. The main contributions in the project consisted of a broad exploration of different literature, focus group discussions and workshops with actors that could inspire before scoping the assignment into a performable task. In addition, a short technological review of relevant implementation frameworks was explored as well, including frameworks such as Netlogo, LibGDX, and Repast Simphony. The results of the pre-study provided the foundation and identified the needs for this master's thesis.

1.3.2 Performed tasks

The tasks performed in this master thesis are:

- A literature review of the topics:
  - Complex Adaptive Systems (CAS)
  - Agent Based Modelling (ABM)
  - Complex system theory within a city context
  - An Architectural approach to complex theory
  - Power grids and storage efficiency
  - Energy consumption and movement behavior within an urban context
  - Literature evaluation of complex system modeling as a method
- An technological evaluation of applications and code frameworks for performing modeling
- An implementation for a prototype of a simulation model used for evaluation
- Expert evaluations with relevant identified stakeholders, conducted as semi-structured interviews

- Identification of the benefits of the simulation model

1.4 Structure

The rest of thesis is structured as follows:

Chapter 2: Literature Review gives an overview of essential concepts, key findings, and development relevant to the research question.

Chapter 3: Research Process and Methodology describes the research process and methodology used in the thesis.

Chapter 4: Existing implementation frameworks describes existing implementation framework.

Chapter 5: Design choices and implementation defines the implementation aims, describes the used implementation framework and provides a design rationale to it.

Chapter 6: Simulations and experiments describes the overall experiment structure, how the experiments were conducted and the results of the experiments.

Chapter 7: Evaluation describes the expert evaluation related to the project, the evaluation methods, the participants and the evaluation results.

Chapter 8: Discussion answers the research questions raised in the introduction chapter, and reflects upon choices made in the thesis.

Chapter 9: Conclusion and Future work summarizes the report and concludes the work performed. Reflects upon experiences gained, what has been learned, and discusses opportunities and further work.

Chapter 2

Literature review

As one of this thesis's objectives is to study how complex system theory and agent-based modeling can be used to model a city context; it is vital to gain a basic understanding of the concepts of a complex system, agent-based modeling, and complex urban systems. This chapter presents the literature that builds the background for the research conducted in this thesis and is a continuation of the literature review performed in the pre-study.

Before the actual literature review, a section describing how the literature review was conducted is presented. The literature review itself is mainly structured into three parts: First off, theory in modeling approaches relevant for the thesis project will be presented, with topics such as modeling methods with CAS and ABM and how these are utilized. This part sets the theoretical background for the modeling methods. Next, the study will elaborate upon a theoretical background that helps build the model, with examples reflecting the context and describe how the theory is relevant, touching on topics such as how a city is a complex system and more. This part provides the theoretical background for helping to build the model. Finally, the study will present the data background for the simulation in this project. This part provides the data basis for building the actual simulation model.

2.1 Literature Review Method

A systematic literature review, according to Anders Kofod-Petersen of the Alexandra Institute in Copenhagen [17], is a formal way of synthesizing the information available from available primary studies relevant to a set of research questions [18].

However, systematic literature reviews are used less in computer science due to traditionally more unsystematic surveys used by methodological frameworks with sets of well-defined steps carried out following predefined protocols.

Kofod-Petersen's article *"How to do a Structured Literature Review in computer science"* [18] provides a description of how to perform one. The article divides a systematic review into three phases; planning, conducting, and reporting. These again are divided into several steps, which can be found in table 2.1.

Phase 1: Planning
1. Identification of need for a review 2. Commissioning a review 3. Specifying the research question(s) 4. Developing a review protocol 5. Evaluating the review protocol
Phase 2: Conducting
1. Identification of research 2. Selection of primary studies 3. Study quality assessment 4. Data extraction and monitoring 5. Data synthesis
Phase 3: Reporting
1. Specifying dissemination strategy 2. Formatting the main report 3. Evaluating the report

Table 2.1: The phases and steps of a systematic review.

When conducting the literature review, a variant of the content shown in table 2.1 was used. Relevant parts of a systematic literature review were adapted as seen fit. Step 1 of phase 1 was performed as a part of the pre-study, with roots in the background and motivation chapter. A lightweight version of step 3, specifying the research questions, was conducted, focusing on identifying how different solutions compare to each other concerning the given approach. Additionally, the research questions revolve around identifying the strength of the evidence supporting the given solution.

For the actual conduction of what Kofod-Petersen defines as conducting the review, the identification of research consisted of acquiring literature relevant to the defined research questions. The strategy this thesis used to find relevant search terms was through different conversations with relevant actors, such as the professor associate from the urban design and planning faculty and actors from the municipality, as well as suggestions and tips from the thesis' supervisor. The archives searched in had its sources in ResearchGate, ScienceDirect, SpringerLink, IEEE Xplore, and more which are considered the most obvious, general, and acknowledged computer science archives. Additionally, Google Scholar, references found in articles of the science archives mentioned earlier, and different university journals such as journals.uchicago.edu and NECSI.edu were used cautiously by cross-checking the facts. Given the time and scope of this thesis, the author of the thesis found this approach adequate. A variant of the strategy of grouping key terms into groups was also adapted, by, for example, combining the terms *"Complex Adaptive Systems"* and *"Urban Planning"* to *"Urban Complex Systems"*.

The step of selection of primary studies deals with selecting relevant articles. The guidelines provide three general removal criteria, including duplicates, studies published in different sources, and studies published after a specific date. In these cases, the guidelines suggest keeping the highest-ranking source. The following step, the study quality assessment, is about filtering away studies that are not thematically relevant to the area chosen, following inclusion and quality criteria.

The last phase results in this thesis report.

The main reason to perform the literature review as it is was due to the aspect of time—a thorough discussion for the topic given in chapter 8.

2.2 Literature on modelling approaches

This section will present the model theory approaches for the thesis. Theoretical background on complex adaptive systems and agent-based modeling will be the focal point.

2.2.1 Complex Adaptive Systems

As reviewed in the pre-study to this thesis, the term Complex Adaptive System embraces a system consisting of several smaller and often simple interconnected parts, creating a complex system with emergent behavior. These components make up networks that interact with each other, usually in a nonlinear fashion. Y. Bar-Yam, the founding president of the New England Complex Systems Institute (NECSI) [19], states that understanding the properties of complex systems, forms the basis of much if not all scientific inquiries [20]. It is noteworthy to mention that Complex Adaptive Systems are a subset of Complex Systems, with the main difference being that the system is adaptable and able to change and learn based on experience and feedback.

Bar-Yam has indicated in several articles that a fundamental goal when studying complex systems is to understand the universality that arises when systems are highly complex [21][22]. Understanding a complex system requires understanding the behavior of the fundamental parts and how they act together for the whole behavior. Bar-Yam further states that defining the different layers of interaction in a complex system is crucial, defining high-level and low-level interactions to gain said understanding.

A central concept when speaking about Complex Adaptive Systems is the term *Emergence*. The formal definition of "emergence" is the process of coming into existence or prominence [23]. In complex systems, emergence refers to the collective behavior and the interaction of individual parts of a complex system, which leads to unpredictable behaviors from the complex system. The collective behavior of the complex system is difficult to determine from looking at the behavior of the individual agents. The definition is derived from the article *"Complex systems theory and evolution"* [24], by Melanie Mitchell and Mark Newman. Mitchell, Davis Professor of Complexity at the Santa Fe Institute, which specializes in the world of complex science [25], has stated that the concept "emergence" is a problematic aspect of complexity due to it being central to complex systems, yet hard to define [26]. Mitchell's standpoint is that there are yet a conceptual framework or vocabulary that are able to characterize the phenomenon precisely, and believes that in the future, as the understanding of complex systems increases, the concepts and vocabulary used for describing them will be replaced by better-defined terms that reflect the phenomena in question.

Generally, it is hard to go by without talking about the Santa Fe Institute of Complexity when speaking about complexity theory. Founded in 1984, the institutes website [27] describes it as the first research institute that dedicates to the study of complex adaptive systems. Their vast amount of researchers [28] aims to understand and unify the underlying shared patterns in different areas of complex systems, spanning from biological systems to social systems. The institute and its researchers provide valuable literature and research for whoever is studying anything related to complexity.

Overall, table 2.2 gives an overview of some characteristics of a complex adaptive system. The characteristics most relevant to the thesis are the ones regarding self-organization, simple ruleset, and unpredictability.

Propery	**Description of property**
Adaptable elements	Elements in CAS can evolve
Attractors	Catalyst in CAS allow new behaviors to emerge
Co-evolution	Progress in CAS occurs with constant tension and balance
Context and embeddedness	CAS resides within and interacts with other systems that influence it
Inherent order	Order is maintained in CAS without inteferred control
Non-defined boundaries	The boundaries of the elements in CAS are blurry and somewhat not defined, allowing for exchange and movement between them
Self-organization	Local interactions create order without direction from above
Simple rules	Simple elements with simple rules can result into broad, complex outcomes
Unpredictability	Behavior is emerging and activities are nonlinear.

Table 2.2: Some characteristics of CAS. Adapted from *"A model of nursing as a complex adaptive system"* [6].

As technology advances, more powerful computing tools have appeared, and more application areas have arisen for simulations of complex systems. Thus, one of the essential positive points for complexity science is the possibility of real-world modeling systems without having to implement the system as a material entity. The importance of having valid and accurate data cannot be overstated to get an as accurate as possible simulation model. If the data provided to the model is inaccurate or insufficient, the output will be the same. By utilizing simulation models, one can avoid risks, costs and save time and resources used. As a result, complex system modeling is utilized in multiple fields for various purposes.

2.2.2 Agent-based Modelling

Concerning complex system modeling, the concept of Agent-based Modelling (ABM) is necessary to get a hold of since the topic of agents is a core aspect of complex system models. As elaborated in the pre-study, ABM is defined as a class of computational models to simulate actions and interactions of agents. The purpose is to interpret their effects on the system as a whole. We recall that A.T. Crooks and A.J. Heppenstall characterizes that agent-based modeling allows the disaggregation of systems into individual components that can potentially have their characteristics and rule-set in *"Introduction to Agent-Based Modelling"* [29].

To get a proper understanding of ABM, some characteristics about the term *"agent"* should be clarified. To summarize, the essential properties of agents are that they usually autonomous and discrete units, capable of processing information and exchanging said information with other agents to make independent decisions [29][30]. Furthermore, Agents can have internal states and properties. They also have the ability to interact and communicate with other agents, designed to be adaptive, and alter their state depending on previous states. Agents can be designed to have an awareness of their surroundings, and lastly, they can be defined to behave based on a predefined ruleset. These rules are typically set based on existing studies and literature, expert knowledge from relevant actors, and relevant data analysis.

Considering agents in complex adaptive systems, they often consist of the same kind of agent, do not need to be very intelligent nor process much data. However, the agents should follow a simple set of predefined rules regarding how they should interact with other agents [29][31]. A common analogy used is ant colonies. Each and in the colony is considered to be an agent [32]. Whenever foraging, each ant moves randomly in many different directions. Whenever an ant encounters a food source, it returns to the nest and leaves a pheromone trail. Ants that encounter this trail are more likely to follow it, leaving a pheromone trail if they find food along the path, thus creating a chain of effect. The pheromone trail disappears if ants do not reinforce it. Each ant follows the rule that whenever it finds food, it forages the food and leaves a trail. The data processed is the pheromone concentration, and as observed, each ant represents an autonomous, discrete unit. They all possess their own internal state, follow a set of rules, have an ability to interact with each other through pheromone, and they have to some degree awareness of their local surroundings.

When discussing modeling with several agents, one should also consider discussing multi-agent modeling, specifically multi-agent systems. Multi-agent systems refer to, according to Jacques Ferber [33], a system consisting of the following parts:

- An environment E, consisting of the following:
  - A set of objects O. Objects can be perceived, created, destroyed and modified by agents.

- A set of agents A. Agents are a subset of objects, capable of performing actions. In short the active entity of the system
- A set of locations L determining the possible position of the objects (from the set O) in space

- An assembly of relations R that links the Objects together
- A set of operations Op, enabling the possibility for agents to perceive, manipulate, create, destroy objects of O, representing the agents' actions.
- A set of operators U with the task of representing the application of the operations from Op and the reactions of the world to this attempt of modifications.

Chapter 3 of the research paper "Multi-Agent Systems and Complex Networks: Review and Application in Systems Engineering" [34] presents in-depth descriptions with examples. Essential extractions here are that Multi-agent models include multiple types of agents, where the focus is on the interaction between the agents rather than only the internal processes of agents and their individual capabilities, in addition to the traditional representation for the individual agents, their interactions, and the environment in which they reside. Thus, the concept of agents is relevant depending on what they are representing, ranging from social systems containing humans as the agent to computer systems with circuit nodes as the agent.

There are no clear thresholds for what sets Agent-based modeling and Multi-agent modeling systems apart from one other when discussing the differences between the two, since multi-agent modeling is often considered a subset of Agent-based modeling. However, Dr. Proverbio of the University of Luxembourg differentiates the two by describing that ABM typically implements lower numbers of more complex agents [35]. The main feature the agents consider is the individual capability to face a task. On the other hand, MAS considers typically higher amounts of less complex agents, focusing on the emergence of new phenomena from social interactions. An example considering network theory that describes the difference is that ABM focuses on nodes of a small network while MAS considers the links of extensive networks.

When is it suitable to use Agent-based solutions? Michael Wooldridge's *"An introduction to Multi-Agent Systems"* [36], describes several characteristics for when such a solution is appropriate. The first characteristic is that whenever an environment is open, highly dynamic, uncertain, or complex, where systems capable of flexible, autonomous action are often the only solution. The second characteristic is whenever agents are a natural metaphor. Wooldridge describes that many environments are naturally modeled as societies of agents, cooperating to solve complex problems or competing with each other. In some situations regarding intelligent systems, the idea of an agent is seen as a natural metaphor. Wooldridge describes the third characteristic as whenever the situation contains some distribution of data, control, or expertise. In specific environments, the distribution of data, control, or expertise means that a centralized solution is, at best, extreme. For such systems, the most convenient way to model is as multi-agent systems. The characteristics suggest that the thesis' concept suits to be modeled this way. Implementation details and design rationale about the agents can be found in chapter 5.2.3.

2.3 The city as a complex system

This section presents the theoretical meta background that helps build the model, with literature that supplements the model's context. The section will focus on how a city system is a complex system, considering it from a complex theory standpoint and an architecture theoretical approach.

2.3.1 A complex system approach

To consider a city as a complex system, a proper definition of a city should be set in place. This section serves as an extension to the review conducted in the pre-study to the thesis. Furthermore, to be able to understand why such a case is suited to be modeled as a complex system, it is important to get a hold of how a urban system such as a city acts like a complex system, drawing a comparison of the two. This section will attempt to shed light on these topics.

The formal dictionary definition of a city, is ***"a place where many people live, with many houses, stores, businesses, etc., and which is bigger than a town"*** [37]. However, an unified definition for a city is harder to discover. The quote *"Cities can be regarded as the quintessential example of complexity"* by Professor and Urban planner Michael Batty [38] gives an indication that the city should be considered to be a complex system. When compared to the complex system theory covered in section 2.2.1, the similarities are many. A city usually consists of several complex sub-systems, ranging from social based systems such as socioeconomic status and government, to physical complex systems such as traffic, power grid, power transportation and so on. A common denominator, is that every system exists to serve the people living in the city.

Batty's research paper *"Cities as Complex Systems: Scaling, Interaction, Networks, Dynamics and Urban Morphologies"* [39] explores how cities weren't really considered to be complex systems until the 1960s, when architects and urban planners began to change their perceptions that cities were functioning economic systems that required social engineering. The focal point was on how the elements comprising the system interacted with each other through structures that kept the system sustainable within bounded limits.

To summarize, the main ideas extracted from the paper are that **cities comprises of sets of components tied together through sets of interaction**, where the archetypal structure is, as quoted *"fashioned around land use activities with economic and functional linkages between them represented initially in terms of physical movement, traffic."* Further on, the paper states that the long-term evolution of urban structure was not central to the early conceptions. The focus mainly lay on how cities functioned as equilibrium structures, more than as complex systems. The primary imperative was on optimizing the interactions between the usage of landmasses while also meeting goals involving social and spatial equity. Transportation and housing were also central parts regarding adopting the argument that cities should be treated as examples of complex systems. Since city systems behave like living organisms that continuously evolve and possess adaptive behavior, it indicates that it is suited to be modeled as a CAS.

Batty also authored an essay with the title *"Complexity and emergence in city systems: implications for urban planning"* [40]. As the title suggests, Batty illustrates how complex theory is applied to cities, drawing comparisons to the two. The essay considers several different aspects on complexity, including topics such as how cities came to be, evolution, transformation and social science. The essay also sheds light on how complexity theory is applicable to cities, illustrating how changes in urban form and function might reveal unpredictable patterns and processes that the author describes as *"pictured in overly simplistic ways"*. Moreover, the essay explores cities through three related perspectives on change, continuity (that contrasts discontinuity and bifurcation, transformation (where forms and functions evolve from one pattern to another) and central to complexity theory, emergence, which is previously elaborated on in 2.2.1, about how new structures come to life.

2.3.2 An architectural approach to complex theory

One can observe an architectural approach to complex system theory in an urban setting from several different essays written by Professor, architect, and design theorist Christopher Alexander [41]. Alexander roots his work in describing the fundamental difference in systems that follow the logic of networked tree-node diagrams. In one of his most acclaimed works, *"The city is not a Tree,"* [42] Alexander uses a street corner with a pharmacy, a paper stand, and a traffic light as an example to contextualize. While people wait for a green light to pass, they probably take a look at the paper stand or decides to buy one. This makes an interactive system, as the different components of the system affect each other and can lead to different combinations of the outcome. While some of the smaller components are static and simple, they can facilitate activities for people, money, electricity, or traffic. Alexander defines this complex system as a city unit. Alexander's thought process aligns with Michael Batty's assertion about cities as sets of elements or components tied together through sets of interactions [39], which was elaborated upon in 2.3.1.

There exists many different combinations of these city units. Alexander differs the main difference in "natural" cities, which have periodically grown through history, and "artificial" cities that have been planned and built in a given time interval. The fundamental difference is how the "natural" cities, such as medieval European cities, grew according to people's natural needs for spontaneous interactions (paper stand example). This need is not as reflected in artificial cities. The most illustrating example is cities designed for car usage, where there are no connections bar highways. These systems are not interactive as they demand intention from the user. If a person would like to buy a paper in such a system, one has to plan for it.

Alexander emphasizes that although cities are complex systems, one should not design them as complex systems. Instead, one should consider the systems to be natural and give space for emergent behavior to flourish within the complex system, which is why cities are suited to be considered complex adaptive systems.

The main findings to extract from these articles are that cities and similar urban structures are very considered to be complex systems with emergent behavior. Such a system consists of various components ranging from infrastructural to social, each with its non-linearity and emergent behavior. Furthermore, one of the most common themes when talking about city systems and urban planning is time. It takes many years to build and form a city and several years on top of that to study the outcome of said changes. Additionally, there are many different actors that are autonomous and discrete units, each with its agenda. These findings implicate that ABM is a suitable tool for studying urban complex systems.

2.4 Overview of relevant data

This section will present the relevant data background on which the model will build on. The section will also supplement various research articles related to building the model, such as theory on the electrical power grid, electricity trading mechanisms, energy consumption within a city, human movement behavior in urban spaces, and more.

2.4.1 Electrical power grid and storage efficiency

The definition of an Electric power grid is the system deployed to deliver electricity from the generating units, such as power plants, to the end-users or consumers, including housing, industries, and office spaces [43]. This kind of system has traditionally been a one-way network, where one has generators that "produce" electric energy that needs to be transmitted over a distance in high-voltage transmission lines to arrive in the distribution network that delivers the electricity to its consumers. The main characteristic is that these power grid elements are interdependent. These networks are subject to a balance between supply and demand, defined as load balance. The demand or load on an electrical grid is the total electrical power being removed by the users of the grid. Whenever excess electrical power during low demand periods occurs, this is stored to be released when the electric power demand rises [44]. Baseload is the minimum load on the grid over a given period, while peak demand is the maximum load. While batteries and other related technologies related to storing electric power has steadily improved over the years [45], a problem that frequently returns is the efficiency of these methods [46][47]. Figure 2.1 generally illustrates that the longer power is stored, the less effective the method becomes. Additionally, transmission losses must also be taken into account. Power-transmission losses can be a severe problem for embedded systems, especially for low-power systems. The losses can be so high that it can results in failure to power the load in the first place.

Another fundamental issue in the power system is the economic approach of potential market failure due to a lack of demand-side elasticity. In the setting of the power grid, inelastic demand means the real-time control problems have traditionally been resolved at the grid infrastructure planning stage, such that the capacity is robust

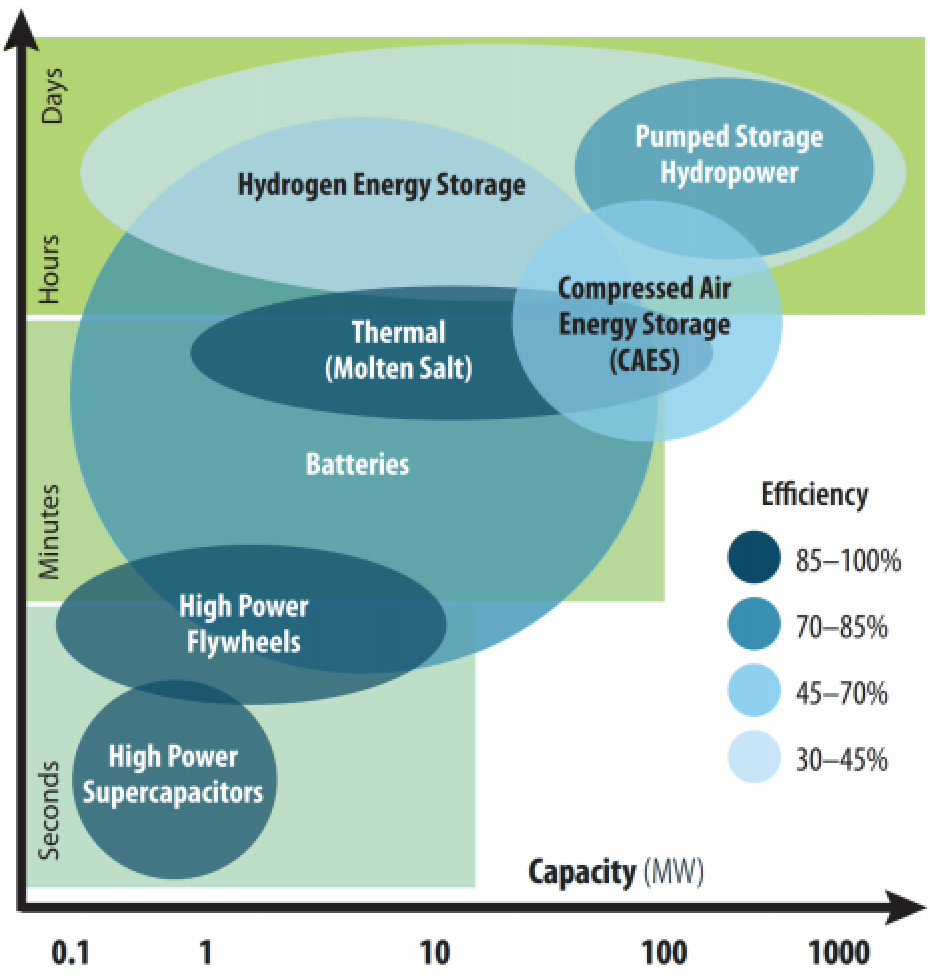

Figure 2.1: Characteristics for different energy storage technologies [1]

adequate to cover the peak load [48]. A study performed by Strbac in 2008 named *Demand side management: Benefits and challenges* [9], illustrated the relatively low utilization of generation and networks, to be about 50% capacity. This result means that there is significant scope for the demand-side to contribute to increasing the efficiency of the system investment.

The result is also supported by Stian Backe's study about distribution of resources through local power markets [48]. Backe's article proposes a game-theoretic approach to solve the challenge in *"Helping end-users help each other: Coordinating development and operation of distributed resources through local power market and grid tariffs"*. The game-theoretic framework is utilized to analyze local trading mechanisms and their feedback effect on the grid tariffs under cost recovering conditions for the mentioned DSO. The article states that it is evident that peak points of energy consumption have drawbacks, where high demand during peak times is still an evident problem. The study provides data and possible solutions for local trading mechanisms at a neighborhood level to solve the problem. It states that *"The peak load is reduced because the local market price reflects the scarcity of capacity in the overall neighborhood"*. The game theory involved is non-cooperative Stackelberg-type games characterized by a leader who moves first, followed by one or more followers acting optimally in response to the leader's decision. The article's main finding is that establishing a local electricity market in a neighborhood Pareto-dominates the situation without a local market. An outcome of a game is Pareto dominated if some other outcome would make at least one player better off without hurting any other player. It indicates that it could decrease the total cost by facilitating local coordination of resources and thus create socio-economic value.

It is also worth mentioning that Backe's study states that capacity-based tariffs are being proposed as a prospective solution, as this is a better representation of the upstream grid costs and creates an incentive to reduce peak load [49]. However, another study performed by Backe, Kara, and Tomasgard [50] illustrates that a reduction of individual peaks may not always be effective at reducing aggregate peak load. The mentioned paper investigates the cost-optimal operation of flexible electricity assets with a capacity-based power grid tariff involving power subscriptions.

This study contributes to the body of literature by investigating through simulations how remote workspaces might affect the global and local peaks.

2.4.2 Energy consumption and movement behavior within a city

For this thesis, when talking about the energy consumption within a city, it is relevant to distinguish the energy consumption of residential areas and public areas. Residential areas refer to geographical areas where the majority of buildings are residential, such as houses and apartment complexes. On the other hand, public areas consist of office spaces, various shops, and some apartments. Industrial buildings such as schools, hospitals, and in general, buildings used for business activities also fall under this category. The differentiation is because of the difference in the quantity of energy consumed in the two groups, as shown in table 2.2 and the article *"Energy Consumption in Households"* [51]. An urban context, such as a city, usually has both of these structures.

The mentioned energy usage includes all energy types used in buildings, such as

	Total	Electrisity	District heating	Other
	kWh/m2	Percentage share		
Total	**230**	77.1	18.1	4.8
3 Office and business building	228	80.7	16.4	2.9
5 Hotel and restaurant building	242	76.9	16.6	6.5
6 Building used for education, public entertainment and religious ativities	190	76.1	17.1	6.8
7 Hospital and institutional care building	313	71.4	23.2	5.3
8 Prison, building for emergency preparedness etc.	207	79.9	12.3	7.8

[1] Building types are classified according to the Norwegian standard, NS 3457, for building types (Martikkelen).

Figure 2.2: Energy use by type of building and energy product, kWh/m2 [2]

energy used for room heating, hot water, cooling, lighting, and electrical devices. The most common energy sources in industrial buildings are electricity, district heating, heating oil, and gas [14]. The statistical report *"Energy consumption in service industries"* provided by SSB [2] shows that temperature is an important variable when explaining energy usage. The statistics also show significant variations in energy use per square meter between different types of buildings. The report states that this can be explained by differences in building constructions, application area, amount of electrical equipment, and the scope of energy efficiency measures implemented. The report presents that the two decidedly most significant energy sources for most buildings are electricity and temperature management. However, for energy consumption in households, there has been a downward trend. Another report, *"Energy consumption in households"* [52], presents data on that reduced oil usage, increased use of heat pumps, warmer climate, and more energy-efficient buildings to be some of the reasons for the downward trend, but for most housing, electricity, and temperature management, similar to industrial buildings are the two most significant energy consumption sources.

While studying factors that might utilize energy sources more effectively, another fundamental approach is to look at how current usage can be minimized. For example, how can a city provide a decent living with minimal energy? The article *"Providing decent living with minimal energy: A global scenario"* [53] takes a more in-depth look into how *"the final energy needed to provide material living standards to the full global population"*. The article defines a set of "Decent Living Standard dimensions," looking at factors such as nutrition, living conditions, hygiene, clothing, healthcare, education, information infrastructure, and mobility.

Relevant to this thesis is the findings related to mobility. The mobility concept is defined as how people can physically change location through different means of transport. Mobility is not necessarily measured on traveling distance but can include the desired frequency of moving from one location to another within a given period. One of the key findings is that people generally use less energy if they are less mobile. The paper states that for mobility-related energy use, 70% accounts for manufacturing and powering vehicles. The remaining 30% is used for producing transport networks' infrastructure such as railways and roads [53]. Three cases back this up, Rwanda, where the regional specificity of their models estimates low mobility and thermal comfort requirements, Uruguay, where mobility requirements were high and thermal comfort requirements were average, and Kyrgystan, where both mobility and thermal comfort requirements were high.

Factors that the article did not cover were the facts regarding the addition of increased mobility. The distribution of people changes, thus leading to a modified energy picture over the area people are mobile. Mobility and energy consumption correlate with where people move to; there will be energy consumed. To understand the consume habits, mobility should be studied as well. The research paper "Human movement behavior in urban spaces" by Willis et al. [54] goes in-depth on what implications human movement behavior has for the design and modeling of effective urban environments. While the article does not take energy usage into account, it surveys individuals' movement preferences within uncluttered environments, focusing on desired walking speed, the distance between others, and general movement trajectories. The study concludes that several influential factors affect how humans negotiate urban spaces and suggest how these factors can be taken into account in attempts to model effective urban spaces for pedestrians. One interesting finding the article discovers is that a majority of journeys conducted are trips to and from work, during the hours between 07:00 and 09:00, and the hours between 17:00 and 19:00. Consequently, people will move more quickly to reach their destination on time during these hours. With this fact in mind, one can assume that the traditional distribution of people within a city differs the most during the hours they transition to and from work, with the addition of errands made after work hours.

This section forms the reference data point for the simulation environment (in terms of building energy consumption data and more) and how the simulation model is modeled. The section also forms the data basis for why the agent's behavior is like it is. In short, the section basically describes why the different parts of the model are implemented as they are. The agents and their behavior are in-depth described in chapter 5.

2.5 Tools for modeling

Recall that the pre-study performed an in-depth technological review of different relevant frameworks for performing modeling, with roots in literature. This section will provide a summary of the contribution to this topic from the pre-study.

2.5.1 Netlogo

Authored by Uri Wilensky and developed CCL, the pre-study discovered that Netlogo is a multi-agent programmable modeling environment. Furthermore, the tool is a recommended tool by the aforementioned Professor Melanie Mitchell of the Santa Fe Institute as of 2013 [32]. Furthermore, it was discovered that Netlogo is particularly well suited for modeling complex systems developing over time. Its strengths lie in the easy-to-understand GUI for performing modeling, as the interface contains pre-defined GUI elements for controlling different factors both for the agent and the environment it was set in. However, the impression of it was not the best due to programming analogies such as turtle-and-patch-orientation. Netlogo's capabilities can, though, be extended from Java, Scala, and other JVM languages. The user manual of the framework and its extension facilities can be found on *https://ccl.northwestern.edu/netlogo/docs/*, and *https://github.com/NetLogo/NetLogo/wiki/Extensions* respectively.

2.5.2 LibGDX

Based on personal experiences, the pre-study reviewed the Java game development framework LibGDX to survey its viability as a modeling environment. In summary, the pre-study discovered that using LibGDX would result in more development time than necessary if LibGDX was used over the other frameworks.

2.5.3 Repast Simphony

Ultimately the framework that this thesis ended up with, Repast Simphony was described as an interactive modeling framework based on Java. The pre-study discovered that the framework was created for modeling and was cross-platform compatible with the most common operating systems. Chapter 4.1 provides a comprehensive description of the framework.

2.6 Methods for modeling energy

The existing work regarding evaluating the method of analyzing energy in complex systems primarily discusses how viable they are. The research paper *"Progress in energy complex system modeling and analysis"* by Wei et al. [55] discusses how energy-economy related complex system models based on macroeconomic theory are convenient to economic analysis. However, it cannot reflect in detail the impact of technological progress nor an understanding of its potential. Another topic brought into question is how energy-engineering models are good at simulating an energy system but meets difficulties when collecting all the technologies' data. As some technologies can only be replaced by primary technologies, thus overestimating the potential of technological progress. It also concludes that when developing energy-engineering models based on bottom-up approaches, which essentially is how one does complex system modeling. It is *"pivotal to analyze the cost of analogies, and it is straightforward for an economic analysis to consider the relationship between the energy sector and other sectors"*.

The most relevant conclusion is how the research paper defines *energy systems* as complex systems involving politics, economics, society, environment, climate, and many other considerations. As it is a complex system, the paper describes that it has characters which the subsystems do not have and that the characters will not be shown by each subsystem when breaking down the whole integrated system. The take here is that the subsystems' analysis cannot explain a whole system's total conductions. As a result of this, one-dimensional models will have their limitations.

The last article reviewed regarding the evaluation of models has the title *"Are complex energy system models more accurate? An intramodel comparison of power system optimization models"* by Jan Priesmann et al. [56]. One of the relevant topics discussed in this article is identifying complexity drivers in the power system optimization model. More complex model formulation does not guarantee a more accurate result, and that complexity can often be reduced. The article explains in-depth the trade-off between complexity and accuracy in energy system optimization models. It defines several levels of complexity, including differentiating between system complexity and computational complexity. The research study concludes that the accuracy of Pareto optimal solutions increases with complexity. The distinction between Pareto optimal and dominated solutions shows that most of the model formulations are neglected when looking at the holistic context. The marginal difference in the form of higher utility decreases along with additional complexity.

The article summarizes a tendency for high accuracy in results requiring a certain complexity of the model. However, models with low complexity can already provide sufficient accuracy.

In summary, based on the selection of the evaluated models, the relevant topics Priessmann et al. recommend for optimization models are

- Simple grid models increases the accuracy moderately and comes with a manageable increase in complexity
- The joint implementation of several technical constraints for conversion (ea. minimum loads) contributes to accuracy but also results in increased complexity
- Intertemporal dynamics such as time coupling constraints increases complexity, and very much if these implementations are combined
- Complexity can be reduced by applying unit clustering followed by temporal and then spatial aggregation without reducing accuracy.

2.7 Research Gap and Revision of the Research Questions

Chapter 2 has contributed to answering research question 1 regarding how complex system models can model an urban system with examples and arguments rooted in literature for why it is appropriate.

Together with topics reviewed in the pre-study, this section illustrates existing research on different approaches to solving problems related to sustainability. One example is through individual aspects, such as FME-ZEN [57], which focuses on zero-emission buildings and neighborhoods at an individual level. Additionally, it touches on the domain of power grids, where a great deal of interest in complex modeling exists, with its potential regarding power grid modeling, especially within the field of smart grids.

This thesis would like to address the research gap based on studying a more extensive picture through an urban planning perspective, considering several different sets of components tied together through different sets of interactions. As the literature suggests that there are limited to no existing available data tied to this topic, a study that addresses this deficiency could be valuable. An example would be the social behavior of people within a power grid and how urban planners can utilize a complex system model to plan cities accordingly. Again, the literature suggests that a tool for addressing such a need is missing.

Regarding research question 2, the literature review identified some relevant end-users but could not identify how said end-user were affected. In addition, the term "end-user" would not be accurate enough for the purpose of this thesis and was thus reformulated into the term "stakeholders." Furthermore, the literature review establishes that the city is a complex system suited to be modeled as a Complex Adaptive System. Support from architectural studies illustrates a need to address city studies as complex system studies. The literature also elaborates on the aspect of time, describing how changes in urban planning do not appear before long after the change has been implemented, which costs a vast amount of time and resources. Thus, there is a need for a tool to help solve such relevant problems.

With the arguments presented, a revision of the research questions is therefore performed:

Question 1: How can complex system models be used as a tool to understand energy distribution within an urban context?

- **Sub-Question 1.1:** Why would such a case be suited to model as a complex system?
- **Sub-Question 1.2:** How can the complex system model illustrate how human movement and population distribution affect said energy distribution?

Question 2: How could a complex system model of an urban context be beneficial for potential stakeholders?

- **Sub-Question 2.1:** Whom would the stakeholders be?
- **Sub-Question 2.2:** What are the benefits?

Research question 1, with its sub-questions, has mainly been addressed in the literature review, but the answer will be supplemented through the implementation. Research question 2 has been expanded to address how potential stakeholders are affected, including additional new stakeholders identified through the evaluation and precisely identifying the benefits of the complex system model. The evaluation interviews aim to uncover the benefits and interest of the simulation as a tool to understand emergent behavior. In short, the research questions aim to study how such a concept can be beneficial as decision support software.

2.8 Chapter Summary

This chapter has discussed several relevant topics, introducing background theory on essential concepts such as CAS and ABM. In addition, the chapter discusses other topics such as power grids, storage efficiency, and city systems in regards to complex system theory and how they are relevant to this thesis. Lastly, the chapter identifies the research gap and refines the research questions for the thesis.

Chapter 3

Research Process and Methodology

This chapter will bring up the research process and methodology used in the research project.

3.1 Research Process

The research project started with an introduction to the problem assignment during the pre-study in the fall of 2020. Reflecting upon the research process, the thesis as a whole mainly followed a process that resembles the diamond process, exploring vast and several different possibilities before narrowing it down to a scoped problem with associated research questions. The research questions, at this point, were constructed to reflect the value of using such simulations, tying together the topics of complex systems, distribution of people within a city context, the associated energy usage, and how this could affect urban planning aspects. During the project initialization, several talks and meetings with different actors related to the problem assignment were initiated, some by the project's supervisor, other by the author's initiative. During this phase, the author established parallel contact with two people from Trondheim Municipality working on the +CityxChange [58] project and Professor Markus Schwai of the planning and design faculty. The talks served as inspiration and a survey to understand needs related to the problem assignment. The literature review at this stage of the project focused on understanding key terms and technologies related to complex system theory.

The second phase of the project consisted of implementation. For this part, the focus lay on getting to know the code framework for the project. This meant going

Figure 3.1: Overview of the research process as a whole

through code documentation and tutorials. The author reached out to the code base's initial creator, Andre Fosvold, to initiate a code review, working through the code together. Implementation to answer the research question and create a functional prototype potential end-users could evaluate was in focus. The implementation methodology followed an iterative and incremental development process by expanding and adding additional functionality to an existing codebase. The idea lay in taking advantage of and understanding the existing code and then implementing the necessary parts for the code to achieve its purpose. The experiment which the implementation set out to reflect revolved around making the experiment evaluable to the potential stakeholders.

For the next phase of the project, a new round of literature review was conducted, expanding the existing literature review with more depth and width by exploring several more related topics to the research project. After conducting the literature review, the thesis attempts to address the identification of the research gap. A refinement of the research questions was done at this point, specifying and expanding the research questions. The refinement concludes the second widening and narrowing of the double diamond process.

For the evaluation phase, the author identified relevant and potential stakeholders of such simulation models and contacted them to investigate whether they were interested in participating in an evaluation. The evaluation was conducted as a semi-structured interview, starting with introducing the research project and demonstrating the model simulation concept, alongside presenting the experiments. The interview template can be found in the Appendix C and focused mainly on the value proposition of the simulation concept. An example for an application of the model had been identified beforehand [59], and the participants filled out a questionnaire inspired by the perceived usefulness criteria of the TAM framework [60] regarding perceived usefulness. In addition, the participants answered questions about the value aspect of the simulation model. How the evaluation is designed will be further elaborated in chapter 7. Additionally, chapter 7 elaborates and analyzes in detail the results and the data gathered.

3.2 Research Methods

The work done in this section is inspired by, and a further development of the delivery of the theory module TDT39, Empirical Studies in IT, based on the book *Researching Information Systems and Computing* [3]. This section will present the research methods used for the project. The description of the research process bases itself on figure 3.2.

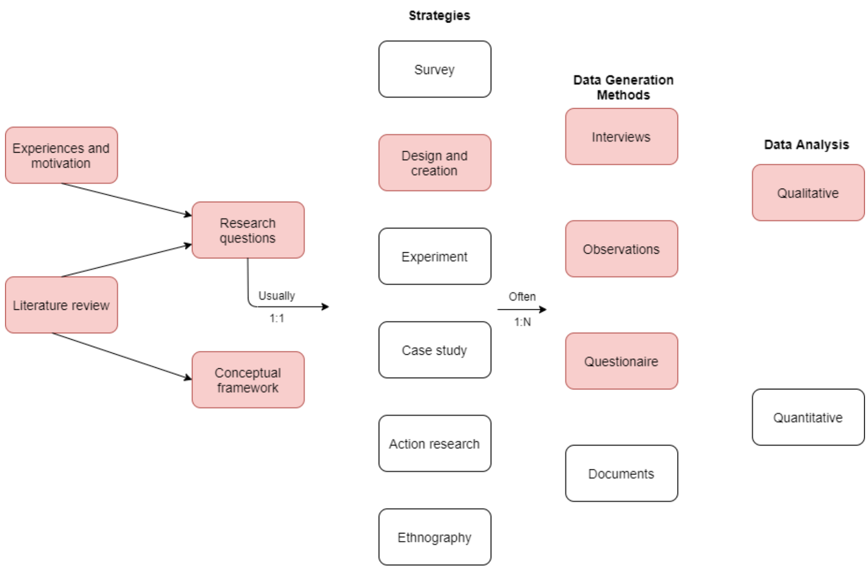

Figure 3.2: The Research Process, adapted from *Researching Information Systems and Computing* [3]

As mentioned in section 3.1, the project consists of several different phases. Different phases of the project might suit different research strategies and data generation methods.

For the first part of the project, experiences, and motivations were explored before tentative research questions were defined. Previous experiences and motivation played a part and created the foundation for initially designing the research questions. Then, after conducting an in-depth, comprehensive literature review of several related and relevant topics, a revision of the research questions was made, further detailing them with the foundation of the literature review. The literature review provided a conceptual framework for the thesis and lay the groundwork for the methodology that consisted of the strategy and the data generation methods chosen to answer the research questions. A more detailed description of the used methods and how the literature review was conducted can be found in chapter 2.1.

The design of the research questions aimed to reflect the utilization of complex system models in urban systems and how such models could create value for the stakeholders, which would be the main contribution of this thesis.

The research strategy for the thesis falls under the category of design and creation of figure 3.2. The strategy focuses on developing artifacts, such as how the simulation model functions for this project. The strategy consists of incrementally implementing a framework upon existing code, designing a suitable experiment to be evaluated by relevant stakeholders. Chapter 5 contains details about the implementation, while chapter 6 describes the experiment.

The data generation method for the strategy is held as an evaluation with identified experts within the associated field. The evaluation is held as a semi-structured interview, with a set of topics to be discussed during the session. A semi-structured interview differs from the classic interview by having a set of topics to discuss instead of fixed questions.

The data generation method for the strategy is a combination of semi-structured interviews, questionnaires, and observations. These three strategies are held as an evaluation with identified experts within the associated field. The evaluation consists of an introduction to the simulation, a semi-structured interview, which differs from the interview by having a set of topics to discuss instead of fixed questions. By the end of the session, a questionnaire is answered by the participant to evaluate the simulation. An in-depth description of the evaluation process is given in chapter 7.

The data analysis is mainly qualitative; given that the participants were interviewed based on their previous experiences within the relevant field, the results are considered satisfactory regarding quality. Furthermore, the results are quantified through the questionnaire and repetitive mentions of specific topics during the semi-structured interview.

The thesis' research paradigm draws characteristics from the interpretive paradigm. As the research strategy of design and creation focuses on developing an artifact used to be evaluated by stakeholders, it is essential to note that as the author of this thesis and as the artifact's developer influences the research. Additionally, with a qualitative data analysis method consisting of several experts' subjective opinions, it will be influenced differently. The project aims to identify the value aspect of how the artifact can be beneficial for an identified group of stakeholders.

3.3 Collection of data

Similar to how the different project stages used different processes and methods, different data collection methods were utilized for the different parts of the project as well. For example, the data collection method for building the simulation model in phase 2 of Figure 3.1 is different from a data collection method for evaluation in phase 4. One, for instance, bases itself on more factual data and studies, while the other is more subjective, based on the evaluation object's past experiences. As described in chapter 2's introduction, different categories of literature were reviewed, and one category included data background for the model. The data collection method for building the model was mainly conducted by reviewing different studies, and thus quantitative.

As described by the end of section 3.2, the data collected for the evaluation was conducted as a semi-structured interview discussing different relevant topics before ending the evaluation session with a questionnaire. Therefore, the data analysis of the data gathered in the evaluation is considered to be qualitative. The evaluation sessions were conducted digitally and recorded through Microsoft Teams, with the consent of the interview subjects. After the evaluation session, a summary extracting the most important aspects of the session was sent back to the participants. Further on, the analysis of the data started by transcribing the interviews, preparing the interviews into textual data. The data was then filtered, extracting the segments that appeared to be relevant for the research. Then, a theme analysis method [61] was utilized, highlighting common talked themes of the participants and discussing the answers.

By the end of the interview, the participant was asked to answer a questionnaire, following a Likert scale [62] to quantify how much they agreed with a set of claims related to perceived usefulness and potential value, utilizing a quantitative analysis method. Finally, the results were presented in a table, presenting the lowest, highest, average, and mode values rated by the participants. The reason for choosing these four was to see the variety of the answers and the frequency for the most common answer.

An interview usually lasted around 45-60 minutes, while the transcription work lasted around 3 hours for each interview. The interview template can be found in Appendix C, and the evaluation process itself is properly described in Chapter 7.

3.4 Participants

The research, which spans data gathering, analysis, simulations, and planning, is conducted by the project's researcher, Dennis Jianbin Liang. The project supervisor is Associate Professor Sobah Abbas Petersen from the Institute of Computer Science, which regularly supervises the research progress. Abbas Petersen is contributing with experience and expertise in modeling, enterprise architecture, and complex systems.

A professor acquaintance from the Institute for Architecture and Planning, Markus Schwai, has been involved in the project as a sparring partner for focus talks, providing insight into urban planning topics from an architectural perspective. In addition, he has provided valuable information and articles relevant to the literature study of the thesis.

Furthermore, representatives from Trondheim Municipality have been involved as a focus group providing relevant information and serving as an inspiration for the project. The representatives the thesis has been in contact with have been working on a smart city project called +CityxChange [58], where one of the goals is to increase the city's activity.

The participants of the evaluation are a set of relevant stakeholders that might benefit from the simulation model concept, identified through literature and focus talks. An in-depth description of the participants and the selection criteria can be found in Chapter 7.1.2.

An application to gather data has been submitted and approved by NSD. Accordingly, all the participants of the evaluation have been asked to sign a form of consent that approves the thesis to gather their opinions as data. The form can be found at Appendix A.

Chapter 4

Existing implementation frameworks

This chapter presents existing code implementations and frameworks of a simulation model that this thesis's code implementation builds on.

4.1 Repast Simphony

Recall that section 2.5 summarized that the pre-study evaluated three frameworks suitable for simulating modeling and simulating a complex adaptive system: Netlogo, LibGDX, and Repast Simphony. When deciding upon a modeling tool, the research article *"Complex adaptive systems modeling with Repast Simphony"* [4] by North et al. was reviewed. The article comprehensively compares Repast Simphony and its capabilities against several other modeling tools such as NetLogo, StarLogo, Swarm, and more when performing complex adaptive system modeling. After reviewing the mentioned article and testing out Netlogo and Repast Simphony, the choice fell on Repast Simphony, primarily because it had the better support system around it and the author's familiarity and capability to implement code with Java. Thus, while Netlogo is one of the frameworks used by Professor Mitchell of the Santa Fe Insitute, Repast Simphony is prioritized over Netlogo for this project due to the framework's unique programming language. Netlogo's programming language bases itself on a programming syntax unfamiliar to the author of this thesis and, from an implementation perspective, consists of basic analogies of turtles and patches. These factors would require substantial effort to build a model from scratch that would suit the project's aim, thus was deemed too time-consuming by the author of this thesis. Another underlying factor was that two previous theses, CitySim, and casEV, were built on Repast Simphony. This is expanded on in section 4.2.

According to Repast Simphony's website [63], the framework is an interactive modeling framework based on Java. The framework is a part of the Repast Suite, a collection of free and open-source agent-based modeling and simulation platforms. The tool itself is created for modeling and has cross-platform compatibility with the most common operating systems, including Windows, macOS, and most of the Linux variants.

The Repast Simphony framework provides user interfaces directed for performing modeling, as illustrated in screen capture 4.1. The interface also provides pre-defined GUI elements that allow for control over different variables and can display simulations in real-time, as illustrated in capture 4.2. Statistics and graphs can also be displayed and updated as the simulations are going on, as shown in screen capture 4.3. Interestingly enough, Repast Simphony can also provide geographic referencing through geographic projections that correlate the agents to positions in space. The agent's representation corresponds to specific geographical features, such as points, lines, and polygons. Figure 4.4 illustrates a Repast Simphony demonstration model that combines GIS with a network.

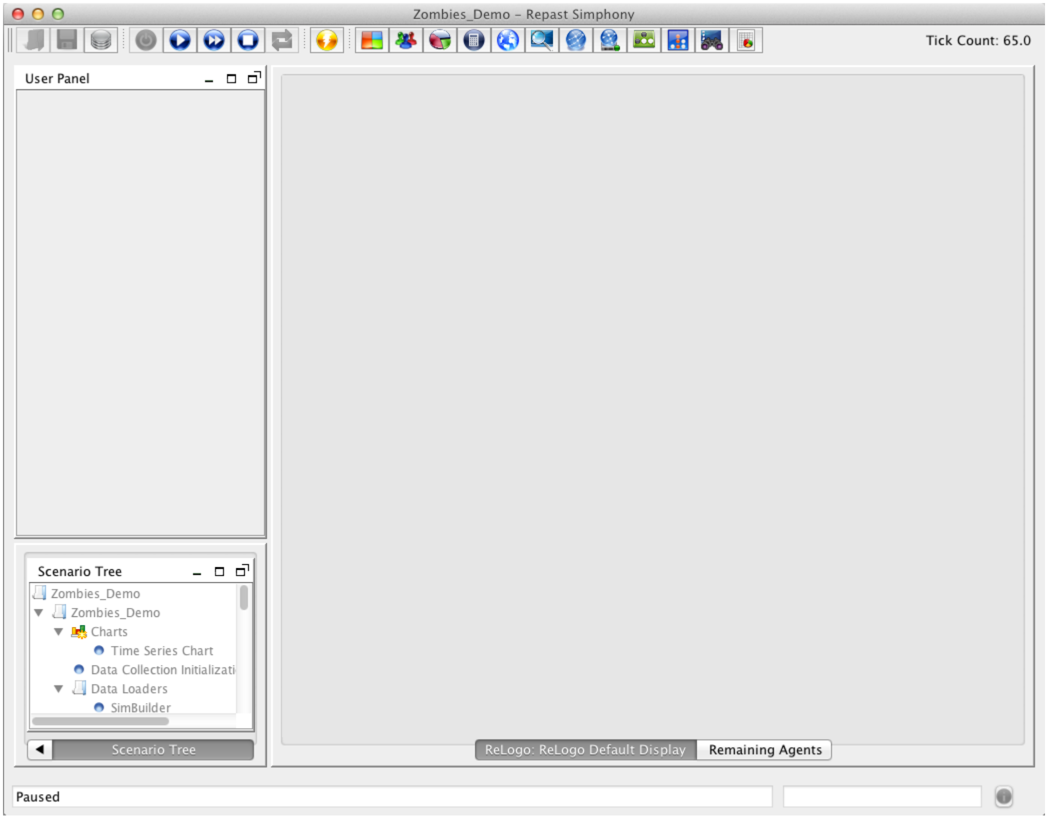

Figure 4.1: Screen Capture of the user interface in Repast Simphony. The screenshots are taken from *https://repast.github.io/screenshots.html*

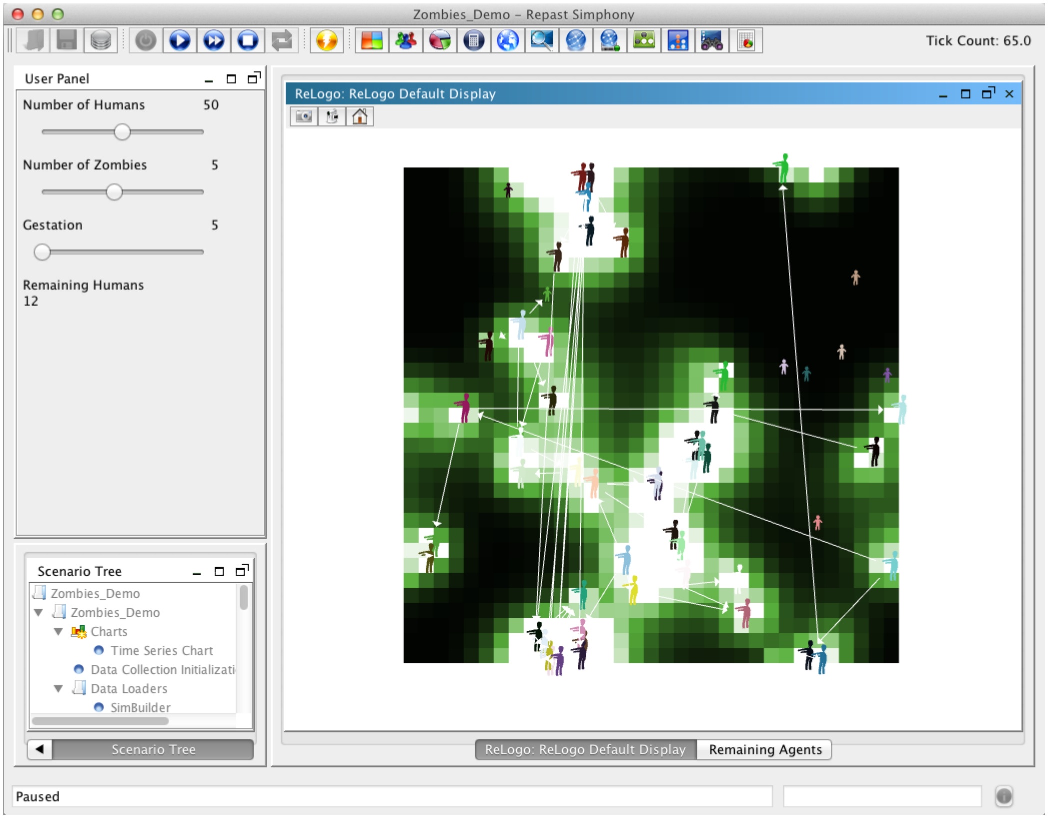

Figure 4.2: Screen capture of ongoing simulation using Repast Simphony. The screenshots are taken from *https://repast.github.io/screenshots.html*

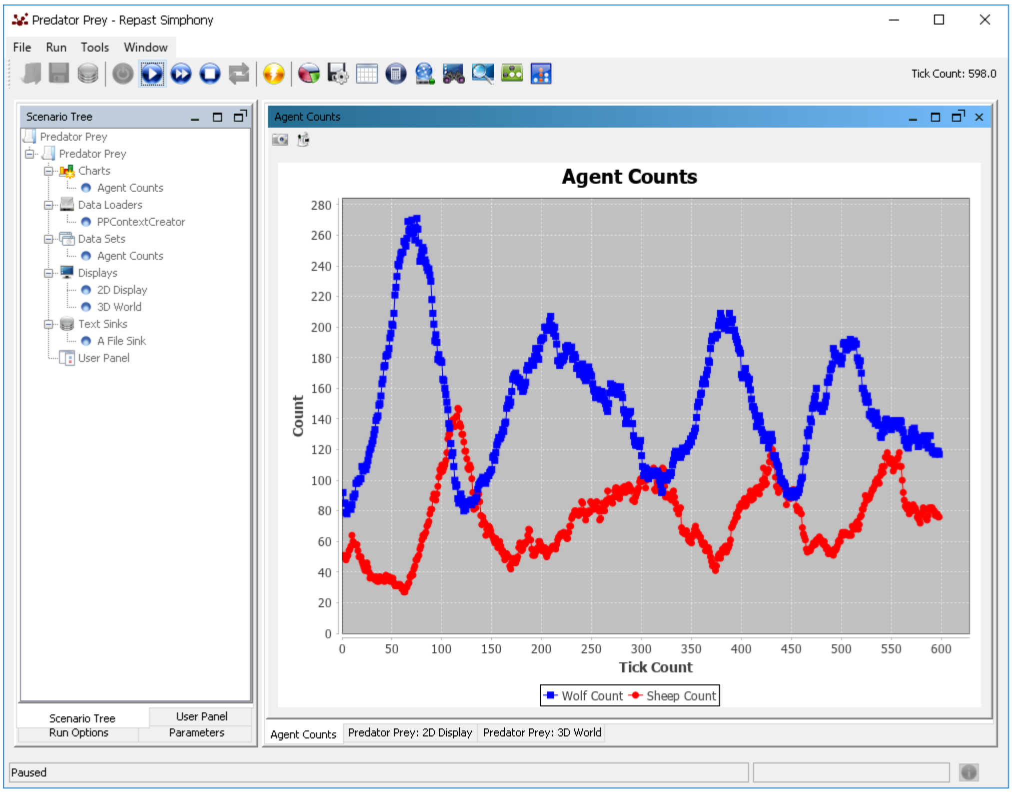

Figure 4.3: Screencapture of statistics from Repast Simphony. The screenshots are taken from *https://repast.github.io/screenshots.html*

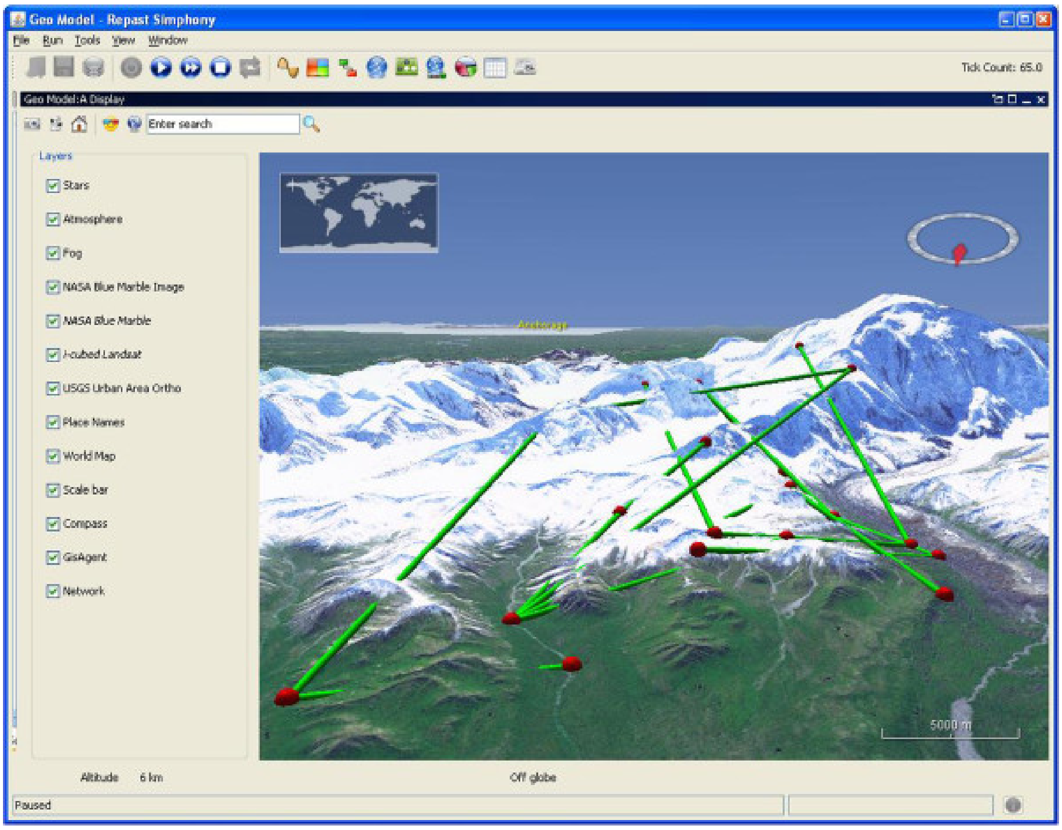

Figure 4.4: Screen capture of Repast Simphony demonstration model that combines GIS with a network. The screenshot is taken from *"Complex adaptive systems modeling with Repast Simphony"*[4].

4.2 CitySim and casEV

Briefly mentioned in section 4.1, the thesis projects CitySim [5] and casEV [64] played a part when deciding on the model framework. CitySim is a modular agent-based simulation created during a master's thesis in 2019 at the Department of Computer Science at NTNU, and casEV was built upon CitySim the following year. The CitySim thesis focused on creating a model simulation that examined the use of agent-based modeling to create a simulation of a city as a complex system. The thesis mainly addressed how agent-based complex systems could help understand emergent traffic patterns and how this would affect a city by studying different variables ranging from dynamic tool booths, available parking spaces, and more. Simulating with different parameters, CitySim managed to observe emerging patterns regarding the inhabitants' traveling habits. Furthermore, CitySim built on a modular approach, making it forward-compatible for developers to use as a foundation for future work.

CitySim consists of different entities that define transportation and mobility in the city and represent agents in an agent-based system. These entities are cars, buses, and people, who interact with the city through traffic systems (the rules of the model) and decide based on past experiences (stored as an internal state, and interact with each other), making them adaptive to the environment they reside within. These properties classify the system as a Complex Adaptive System, making the system both complex and adaptive. CitySim aims to reveal patterns that emerge from how agents interact with the given environment and how the patterns that affect the environment might impact the agents' decision-making through different simulations.

casEV, on the other hand, builds upon the pre-existing, defined CitySim framework. Moreover, the framework in question is inspired by the CASCADE framework, borrowing the idea of Prosumers and Aggregators to handle energy trading between agents and the power grid. casEV mainly consists of three modules, a physical, a market, and an agent module. The modules represent all physical elements, communication between prosumers/aggregators, and the agents, respectively. casEV aimed to study what benefits V2G charging could provide concerning the transportation of people in electric vehicles within an urban context. Note that eCim, similarly and in parallel to casEV, builds on the existing code framework of CitySim, expanding upon its features.

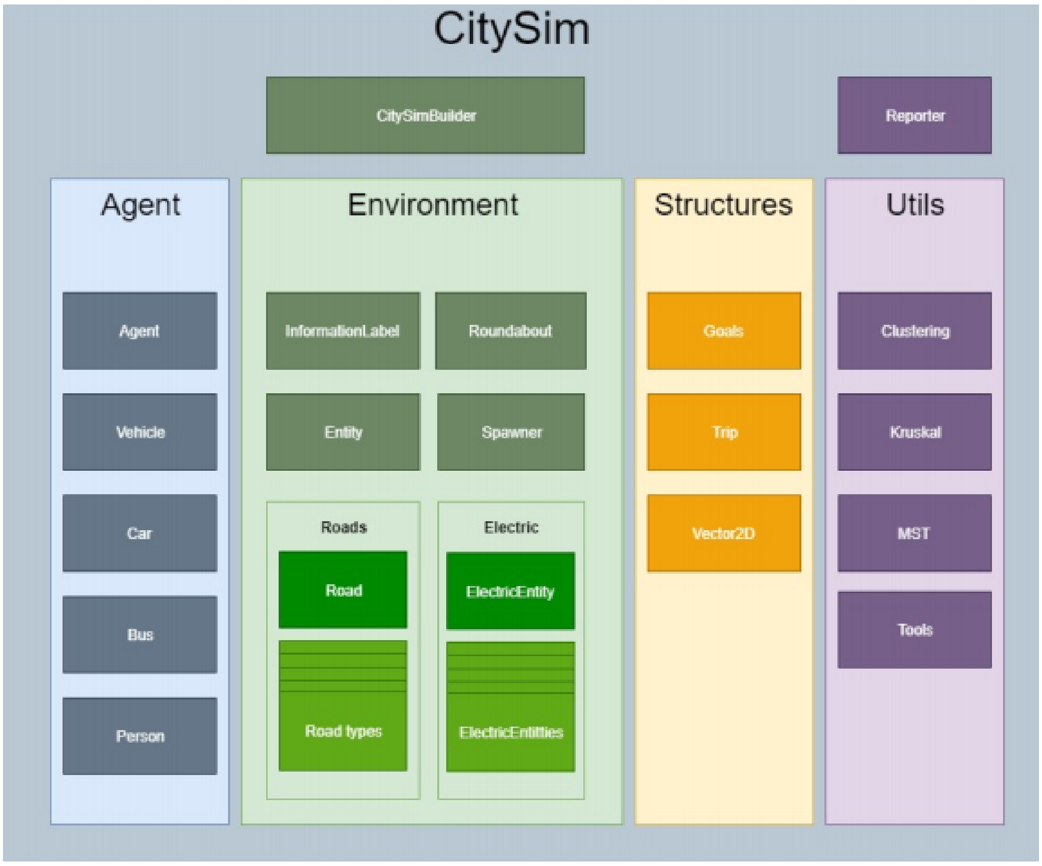

Figure 4.5: An overview of CitySim's project structure, showing the relevant packages and classes. Provided by CitySim's author [5].

Diagram 4.5 illustrates the code structure for CitySim, which casEV builds upon in the two previously mentioned projects. Note that similar to most simulations, both models are simplified representations of reality.

Observe that CitySim is mainly structured into four different package categories; Agent, Environment, Structures, and Utils. The package structure reflects how the code implementation is performed. The agents of the model are the different vehicles and the people of the model. The vehicles are goal-driven agents that possess an internal list of sub-goals they follow to achieve their end goal. Implementation-wise, this is performed using the A*-algorithm [65] located in Utils/Tools. The people in the model framework also possess an internal state with goals and objectives. Similar to how agents in complex adaptive systems act, their decision-making is adaptive and affected by previous results.

The environment package consists of the elements that build the project's physical entities, such as roads, roundabouts, buildings, and more. Implementation-wise, the environment is created at initialization of the model, generating a physical environment by reading different image files, pixel by pixel. Each of the different element classes in the environment package is color-coded, and the initialization class file, CitySimBuilder, creates the environment based on the pixel in the image file that matches the different classes, as shown in figure 4.6 and figure 4.7.

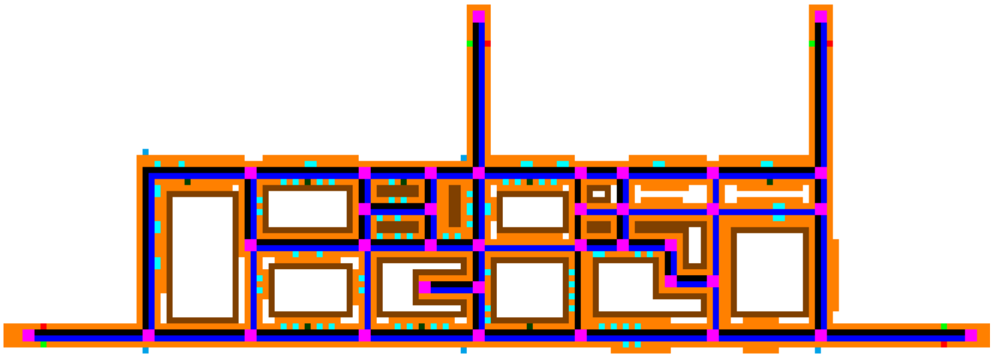

Figure 4.6: Example input image file

Figure 4.7: Output file in the simulation created from input file from figure 4.6

The structures package contains the different data structures of the whole code basis, while the utils package contains convenient utilities, tools, and different algorithms for the implementation.

4.3 Chapter Summary

This chapter examines the different relevant frameworks considered for the project, as well as what framework the project settled on. The chapter also elaborates on previous existing work that this thesis project builds upon.

Chapter 5

Design and Implementation

With roots to chapter 2, this chapter will present the proposed design and implementation of the designed complex adaptive system model. As presented in Chapter 1 section 1.1, and later refined in Chapter 2, one of the project goals was to achieve a conceptual model for simulating and analyzing the activities within the defined context in order to evaluate the model with relevant stakeholders. The model aims to present the interaction between population distribution and electricity usage. In addition, the model will serve as a means to help answer RQ1 with its associated subsequent research question. Therefore, this chapter will also present the model framework used to perform the modeling, alongside previously associated projects.

5.1 Implementation aim

As briefly touched on in the chapter introduction; the implementation aims to serve as a means to help answer RQ1 with its refined sub-questions. The implementation and its belonging experiments will attempt to study the interconnected connection between human movement and energy motion, more specifically, electricity within a city context. It will also aid in answering RQ2 by being the "object" evaluated. It will also directly achieve Goal B about achieving a conceptual model for simulating and analyzing activities within a defined city context and supporting achieving Goal A (in the same way as RQ1) and Goal C of identifying needs and specific valuable assets.

The city context will be studied as a complex adaptive system, as argued why it is suited to do so in chapter 2. The experiment will give a value context that identified stakeholders could relate to and evaluate. The studied context narrows down to the movement of agents, how the electricity usage will act along with it, and how different factors such as travel time change accordingly.

5.2 Proposed code framework

The proposed code framework for this thesis is constructed by expanding and implementing existing features into the existing model CitySim, similar to how casEV performed its implementation. The code can be found at https://github.com/dennisjl/thesisCode. Consider eCim's implementation as a parallel branch to casEV. The focal point when creating the code implementation, as indicated in section 5.1, lay in creating an evaluable situation for the model to be evaluated by identified stakeholders. Thus, the implementation focus lay in enhancing the existing model of CitySim, with necessary features in order for it to reflect the desired situation. One of the main reasons to do so was that CitySim already was a solid framework that needed a few modifications to achieve the desired research purpose. Therefore, choosing to enhance the existing framework made logical sense due to time constraints and ameliorating the workload. Figure 5.1 shows an overview of eCim's proposed framework structure.

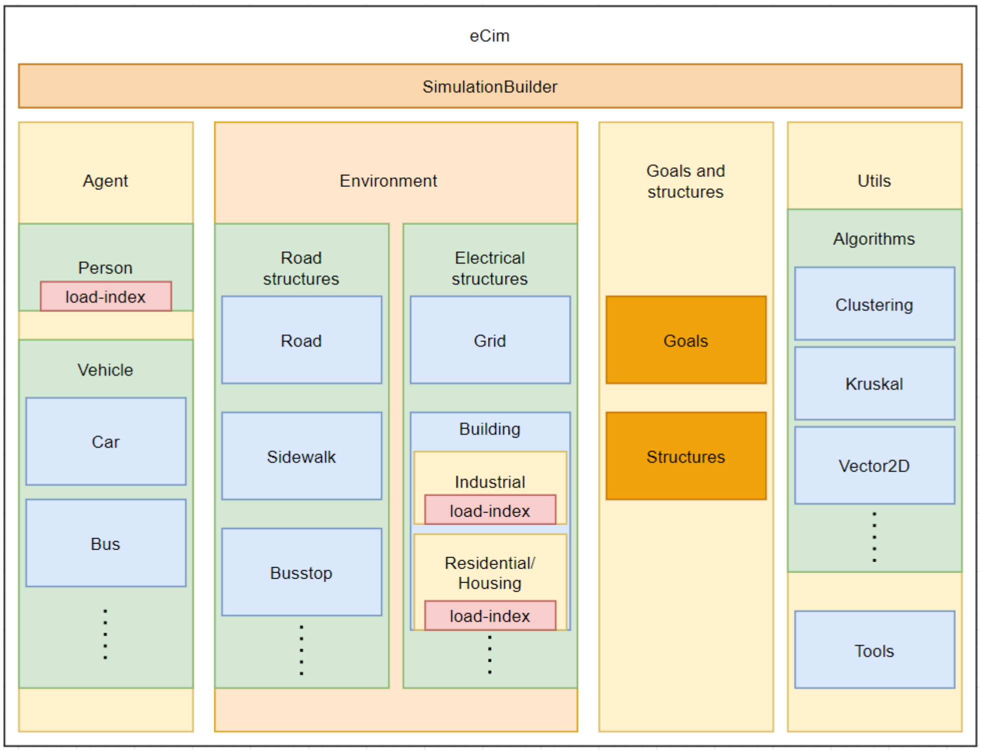

Figure 5.1: An overview of the proposed frameworks structure

5.2.1 Design Rationale

As mentioned in Chapter 3, the implementation methodology followed an iterative and incremental development process. This implies expanding and adding additional functionality to the existing code basis of CitySim.

RQ1 was in mind when performing the following implementation changes. First off, the building class was expanded to include industrial buildings and residential buildings. The housing and industrial building class was added to fulfill this purpose. Additionally, a building load index was added to the building superclass, indicating how much electricity the building uses. During the nighttime, the index is reduced due to less activity in the building. Additionally, the agent-class was modified for each relevant agent to contain a load-index used to calculate the total electricity consumption whenever an agent spawns in the simulation. The consumption change is illustrated in the associated data graphs of the simulation.

Next, after discussing with an associate from the architecture and planning faculty, two new physical geographical locations were designed. The main arguments for doing so revolved around the simulation's existing area not being active enough. In order to get a precise simulation, it is essential to have an accurate representation of reality (this applies to other elements of the project as well). Although the existing location was located in the city center, the location was considered to be in the outskirts. The building typology consisted of a combination of residential and industrial buildings, where more than 50% of the building's functionality was residential. In section 2.4.2, it was also established that there was a significant difference regarding the quantity of energy consumed between the two types. A clear distinction of the different building types was deemed necessary to keep the concepts as straightforward as possible to get a proper evaluation with no confusion. Therefore, two geographical locations were created to reflect the distinction. Moreover, the road entry points to the physical location were not considered to be central enough. The existing road entry points are roads connected to the existing road network of the city, meaning that the continuous traffic flow is from within the city rather than from the outside.

The new city area is central, consists of more industrial buildings, and has transport veins and city hubs directly in the city center where people enter the city. The chosen residential area was chosen due to an assumed population that would use transport into the city such as cars and public transport. The contents of the new geographical area are elaborated more in-depth in section 5.2.2.

Regarding data visuals, new data charts were implemented to reflect the experiment. Charts showing the building load index of the buildings in the simulation and the occupants in the different buildings were implemented. The context file of the simulation was modified to show the new environment the simulation takes place in, allowing for the different agents to navigate in the simulation model. Additionally, an experiment handler was added to handle the different experiment cases more efficiently. The handler's functionality is to initialize the different cases related to the relevant experiments. Figure 5.2 shows how the different parts are connected to each other.

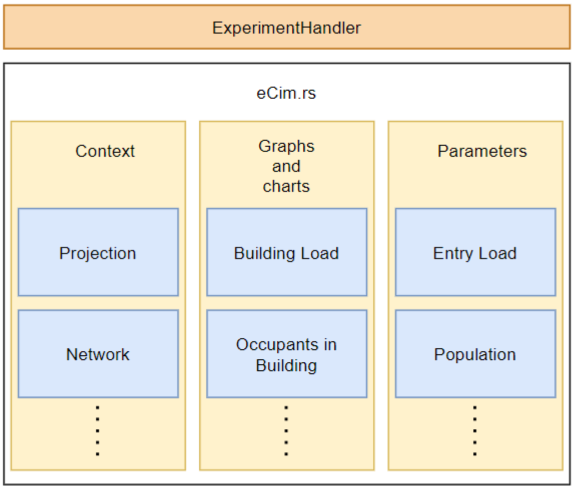

Figure 5.2: Experiment handler and chart etc

5.2.2 The environmental design of the model

The environment in question consists of roads, industrial buildings, residential buildings alongside other entities such as bus stops, parking spaces, and more. Figure 5.3 grants a simplified overview of how the different parts of the environment are connected. The model uses a manually drawn .png image file to initialize the environment, drawing the context of the model pixel by pixel. Figure 5.5 illustrates the output as seen during a simulation of the proposed complex system model. Finally, all of the model elements are composed together in the "CitySimBuilder.java" file, building up the complex model simulation of the city.

The Entity class

The "Entity"-class is the superclass of all environmental structures in the implementation. All environment structures extend from the "Entity"-class and inherit

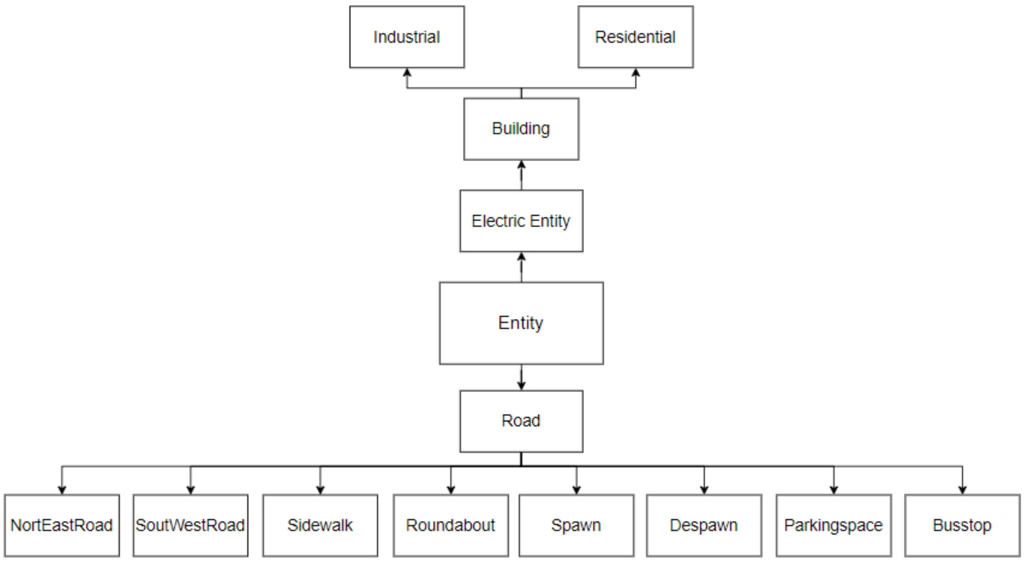

Figure 5.3: Simplified class relation diagram for the the environment build

the GridPoint location property, which describes wherein the implementation space an element is located.

The Road class

The "Road"-class of the simulation is a subclass of Entity. A "Road" is a space that hosts vehicles. As observed in figure 5.3 the "Road"-class is a superclass to a variety of different classes. Each of its subclasses is a specification to facilitate a specific movement behavior of the vehicles and aid the environment's setup.

The Nort-East and the South-West Roads

Essentially the same type of object, but split into the respective classes due to management of the model's different directions. By implementing this detail, vehicles that drive towards each other in the different lanes can perform a collision test based on the road type instead of a linear calculation. If the other type of road hosts the vehicle approaching, it is ignored and drive as standard.

The Sidewalk

While the sidewalks are a subclass of Road, it is unique because it is implemented such that the defined vehicle subclass cannot occupy it. Sidewalks are the locations where people get out of the car or bus.

The Roundabout

The roundabout consists of the roundabout object and the road, as it is a part of the road system. The object consists of a center and keeps track of the roads connected to it. The roundabouts function follows an equation that computes the cross products of two vectors, discovered by CitySim [66], as the roundabout class CitySim created was adequate for eCim's purpose of being a road element.

The Spawn and Despawn

The Spawn point and Despawn point are opposites of each other where the spawn point initializes the vehicles. The "Spawn"-class consists of two FIFO-queues, the "vehicleQueue" for vehicles waiting to enter the environment and the "busQueue," where people wait for the bus. The class runs every tick to check whether there is space to spawn a vehicle. It will spawn a vehicle whenever space is free and within the set time intervals. Whenever a bus spawn, it will add people to the bus queue up to max capacity before spawning. The despawn class removes all the vehicles that enter the despawn point and activates a flag, signalizing the end of the trip.

The Parking Space and Bus stop

The parking spaces are spots in the environment that keep track of whenever a car vehicle occupies it. The bus stop is the same, but only for busses, allowing people to enter and leave it. In short, the parking space and bus stop are road spot that allows for a vehicle to occupy it. The spot connects to all adjacent road types connected to it. The despawn class behaves similarly to a parking space class.

The Electric Entity

The electric entities are also a sub-class of the "Entity"-class. The "ElectricEntity"-class has the properties of keeping ahold of the total building load and updating any changes to it.

The buildings

The "Building"-class acts as a destination for the agents of the model, as well as an electric entity. The class keeps ahold of the object's identity, the location in the environment, and a list of occupants. The "Building"-class is divided into two sub-classes, the Industrial building class and the residential building class. The sub-classes keep track of the electric consumption, the base value, and the value based on each occupant in the building. The values are updated on each tick whenever people enter or exit a building.

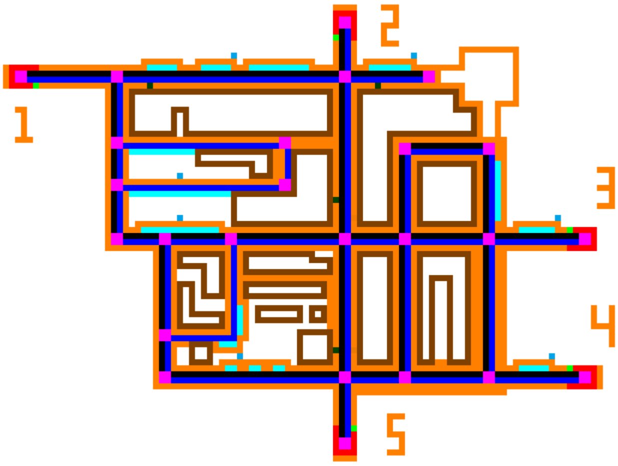

Figure 5.4: Environment inputfile

	Spawn point for Agent
	Despawn point for agent
	North-east road
	South-west road
	Sidewalk
	Roundabout
	Bus-stop
	Parking space
	Industrial building
	Residential building

Table 5.1: Color overview of the pixels that creates the environment of the model

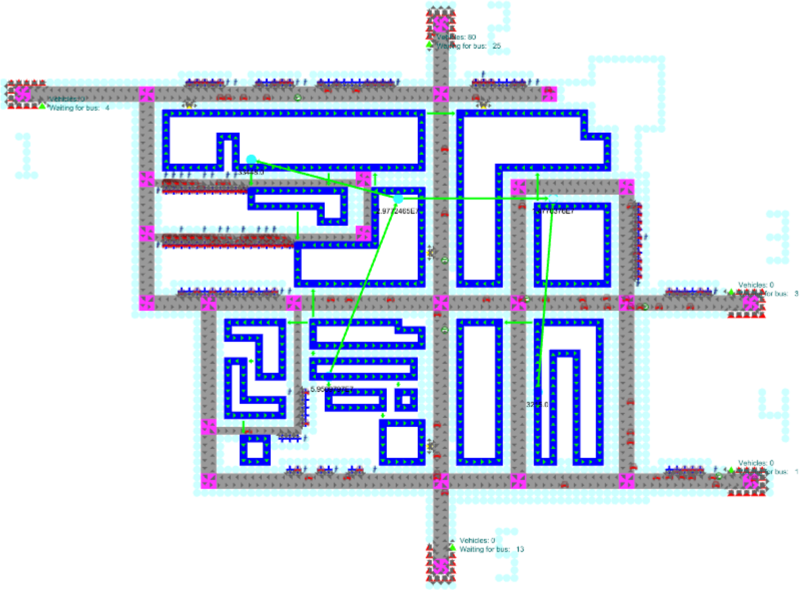

Figure 5.5: Environment during a simulation

The environment of the model is twofold. The first part of the environment is modeled after a high activity area in Trondheim City center, chosen after consulting with actors with relevant knowledge within urban design. The narrowed area consists of various buildings with different functions, such as office spaces, shopping malls, and educational institution buildings. Additionally, the area itself was considered to be a highly active urban area within Trondheim City. Figure 5.4 shows the raw .png image file used to initialize the environment.

The second part of the environment model is a hypothetical, nonexisting area with inhabitant density inspired by a residential area near Moholt. The area resembles the first area geographically, but residential buildings replace industrial buildings. The choice to use a hypothetical residential area was mainly due to the small value gained by sketching a new geographical area from nothing, and to lessen the workload of creating a second image file. By replacing the industrial buildings with residential buildings, the hypothetical scenario still conserves as somewhat realistic, as the geographical size would be somewhat similar to the inspired residential area. Figure 5.6 and 5.7 shows the input and output files of the residential area.

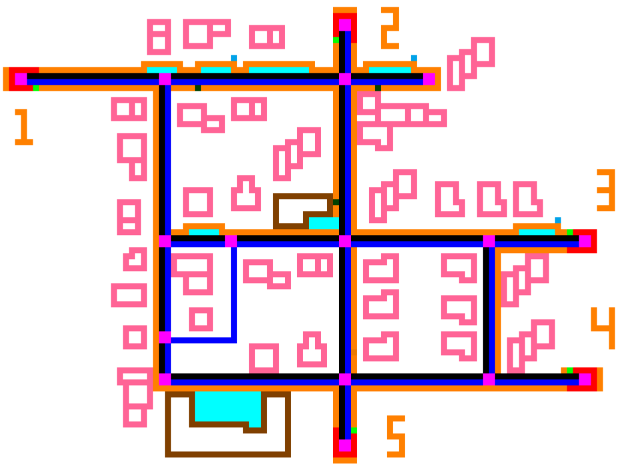

Figure 5.6: Input file of the residential area

Figure 5.7: Residential area during simulation

The agents in the model spawn from five different spawn points, correspondingly to the spawn points in the residential area connected to the high activity urban area.

5.2.3 The agents

Recall that chapter 2.2.2 established that the thesis' concepts were suited to be modeled as a complex adaptive system using ABM. Traditionally, agents in CAS are typically not intelligent and consist of the same types. The situation the thesis sets out to model consists of several types of agents with varying degrees of intellect. A multi-agent system is to be combined with CAS to observe in a simulation. The system simulates as a combination of MAS and CAS.

The agents in the model consist of the different vehicle types and persons. The behavior of each individual agent is relatively unintelligent. However, each agent is an autonomous and discrete unit with its respective internal state and property. One challenge when modeling the agents was finding the right balance of making them un-intelligent and inefficient enough to follow the principles of CAS, but at the same time, be realistic and consistent in the system. Every active agent of the sub-category person follows the pre-defined ruleset of reaching their destination and consuming energy in the model, utilizing a vehicle for its travel. For example, whenever a person-agent enters a building, it will add its load index to the building's load index. The exception is when an agent resides in their respective residential building (housing) during night hours, where the load from the agent is set to zero. The choice of transport utilizes the same probability model defined by CitySim [5], as this was adequate for eCim's purpose.

On the other hand, the vehicle agents utilize the road network and the environment to move around, only moving on road structures and their subclasses. The vehicles are designed to have two properties of awareness for their surroundings; one is sensing the environment, and the other one is sensing other agents around them. The vehicles will stop and wait if the vehicle in front of the implementation queue stops to not collide with each other. An overview of how the agents are structured in relation to each other implementation-wise can be seen in diagram 5.8.

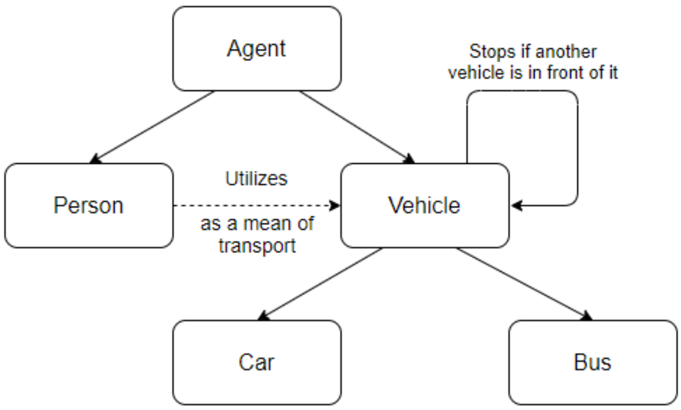

Figure 5.8: Simplified class relation diagram for the agents

The total population of the model is static and is initialized at the start of the simulation. The population is set to be a default start value but can be adjusted in the Repast Simphony GUI. Elsewise, the eCim simulation model bases itself on CitySim's population model [5], as the ratios were rational for the purpose of eCim's simulation model. Furthermore, based on the movement behavior study in the literature review 2.4.2, the 75% distribution of workers seems plausible. Additionally, the simulation model accounts for that most of the journeys are conducted between the hours 07:00 - 09:00 and the hours 17:00 -19:00, as 2.4.2 describes.

5.2.4 The GUI

eCim runs its simulation using the user interface in Repast Simphony, as illustrated in section 4.1, Repast Simphony allows visual display of the agents' programmed "normal" behavior in the environment, and at the same time, provides real-time graphs of data captured during the simulations. A short demonstration of the simulation is provided in the video link: https://www.youtube.com/watch?v=5UwHa19lBAI, and figure 6.1 shows the overall simulation picture during a simulation. An electric meter and a simulation clock are manually created (as in hardcoded) and provided in the upper right corner of the simulation model. Some parameters are predefined from the code implementation but can be modified before each simulation in the left side menu of Repast's GUI. Repast Simphony also allows for exporting the simulation results in a graphical format after each simulation.

Chapter 6

Simulations and experiments

This chapter introduces and shows the results of the three experiments shown as examples to the evaluation participants. The chapter also briefly discusses the results of the experiments. Subsequently, this chapter also assists with answering SRQ1.2 of RQ1 of how the simulation model can show how energy distribution is affected by movement and population distribution.

6.1 Experiment structure

When designing the experiment, it was essential to pick a situation that could show the capabilities and possibilities of the complex system model. As the simulation model was built incrementally upon the existing framework of CitySim, properties such as traffic simulation data from CitySim were available to use as well in the experiment demonstrating the abilities of the simulation model. Together with eCims additional features, an experiment containing working remotely from residential areas was included. This specific scenario was picked due to its relevance as of writing the thesis amidst a pandemic.

The experiment was divided into three different cases; the first case consists of requiring the workers in the simulation to works as usual by entering the city area and their respective onsite office spaces to work. The second experiment took into account where 50% of the population had to stay home, and the other half to work onsite. Finally, the third experiment considered that 75% of the population stayed home while the rest went to work on site.

6.2 Results

Figure 6.1 illustrates the overall simulation model during a simulation run, while 6.2 and 6.3 shows a zoomed-in version of the two areas. As previously mentioned in 5.2.4, a video capturing the simulation model when running can be found at the following link **https://www.youtube.com/watch?v=5UwHa19lBAI**.

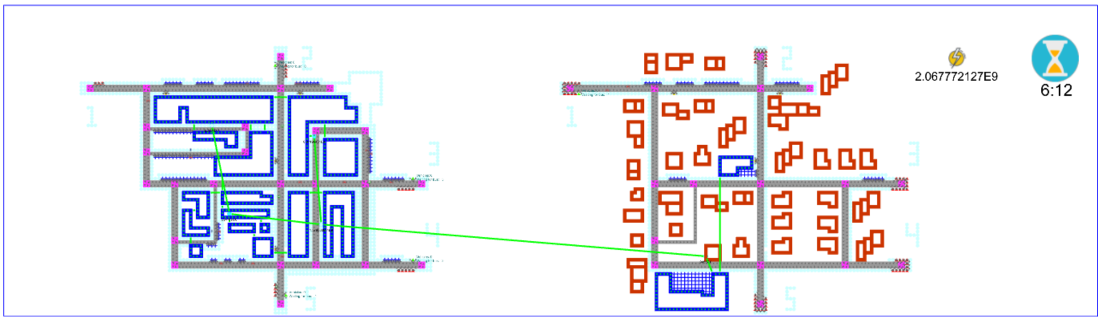

Figure 6.1: The overall simulation picture

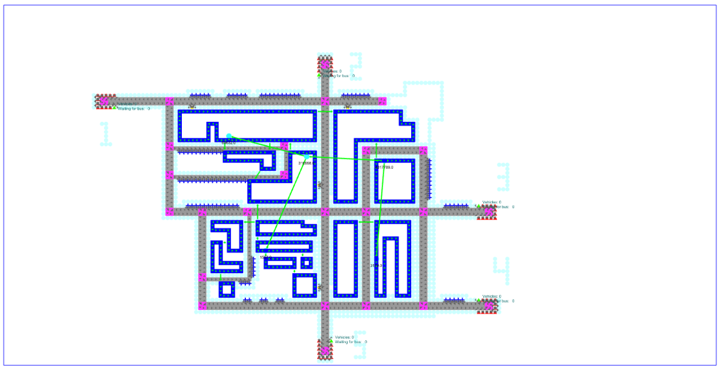

Figure 6.2: The display of the city area during simulation

Figure 6.3: The display of the residential area during simulation

6.2.1 Experiment 1

The first experiment requires all of the simulation's workers to travel to and enter the industrial buildings. The time axes are measured in ticks due to the simulation performing one step per tick. 10 000 ticks measure to about 24 hours in the simulation. Figure 6.4 illustrates the occupants of industrial buildings. Observe that during the morning hours, a spike happens due to agents entering the different industrial buildings of the simulation. During the day, the count of occupants varies a bit due to workers' and shoppers' distribution, where some enter and others exit. The next variation happens at the end of the workday. This is due to the different work hours of the workers, other workers running errands moving from one building to another, and more before moving back to their respective residential areas. Figure 6.5 shows the count of the residential buildings, which shows an almost inverse pattern of figure 6.4.

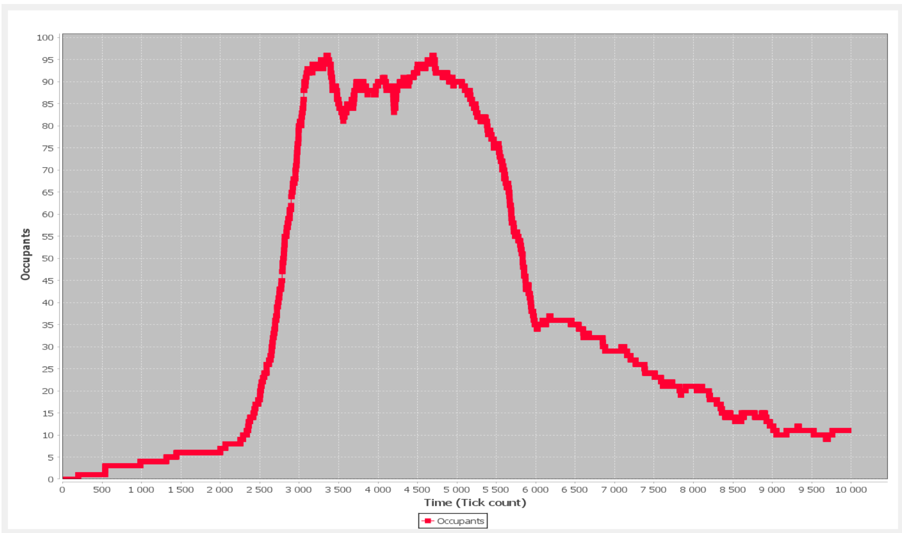

Figure 6.4: Experiment 1: The occupants of industrial buildings

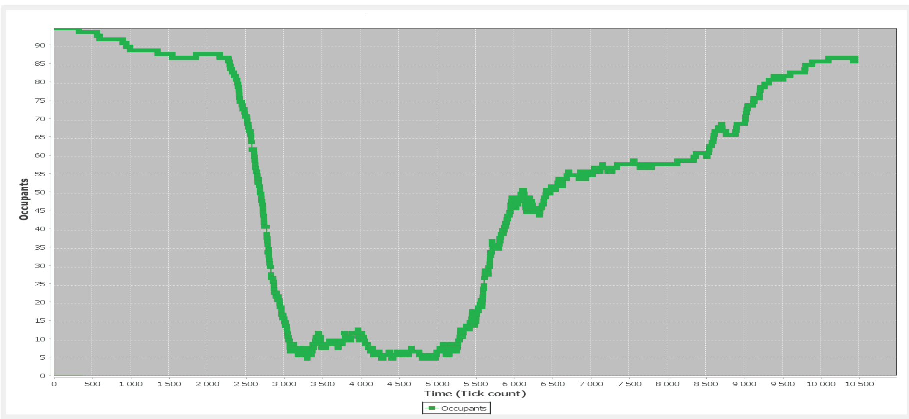

Figure 6.5: Experiment 1: The occupants of residential buildings

Figure 6.6 illustrates building load for the industrial buildings in the simulation, while 6.7 shows for the residential buildings within the same time interval. Figure 6.8 shows the building load for the whole simulation picture, combining the residential building loads and industrial building loads for the period. Recall that each person in the simulation got a load index which affects the total load. Figure 6.9 presents the average travel time of the agents in the simulation.

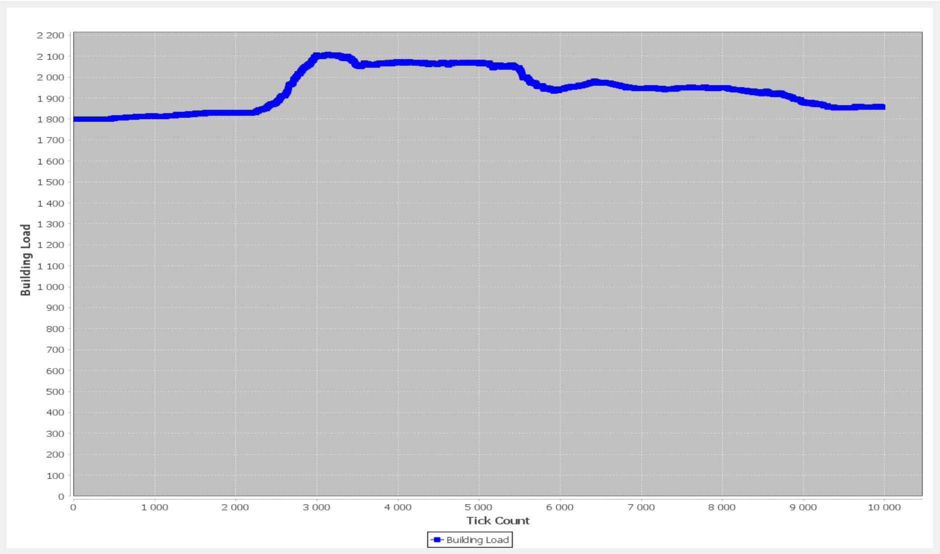

Figure 6.6: Experiment 1: Building load for industrial buildings

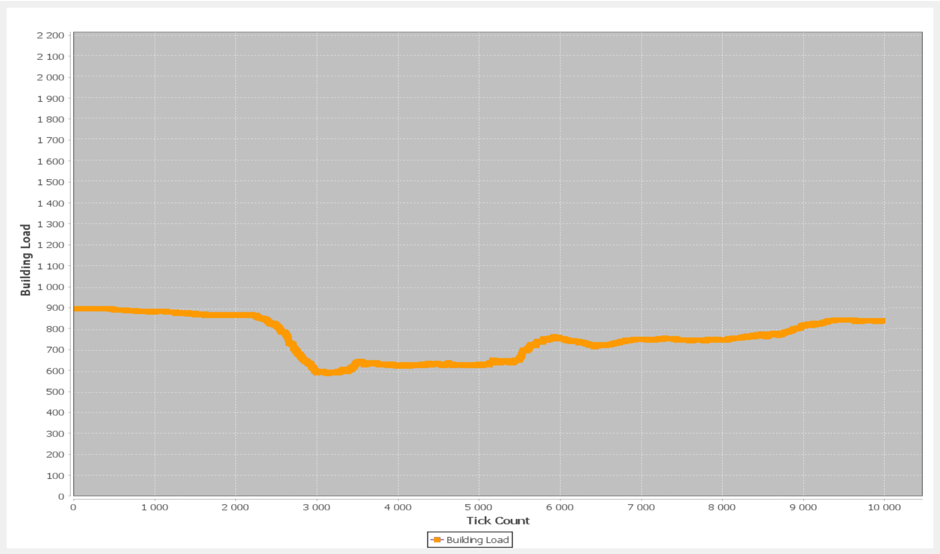

Figure 6.7: Experiment 1: Building load for residential buildings

An interesting observation can be found in the combined building load in figure 6.8. The dents in the graph are due to the agents moving in and out of the industrial and residential buildings, creating deviations in the simulation picture's overall building load.

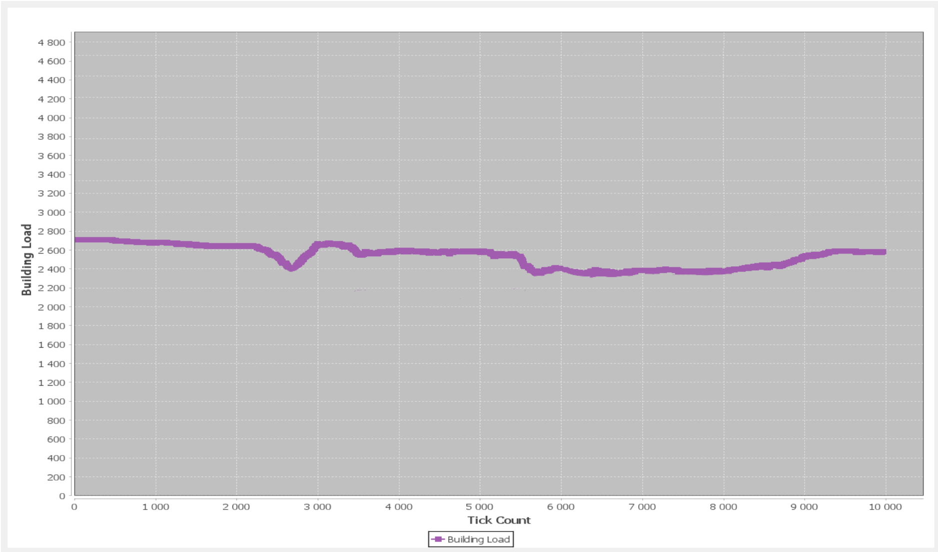

Figure 6.8: Experiment 1: Combined building loads

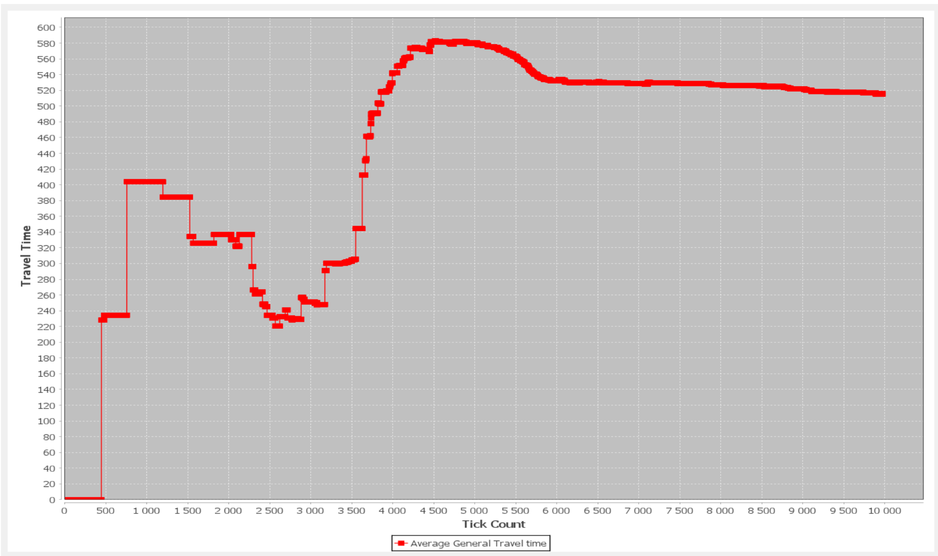

Figure 6.9: Experiment 1: Average general travel time

6.2.2 Experiment 2

Experiment 2 simulated the situation where 50% of the population worked from home, while the other half could travel to their workplace and work from there. The results of the simulation were as following:

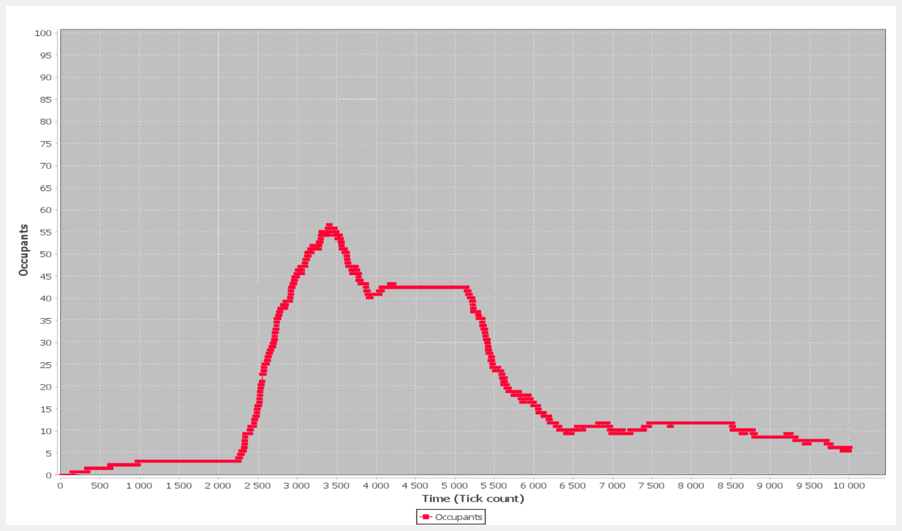

Figure 6.10: Experiment 2: The occupants of industrial buildings

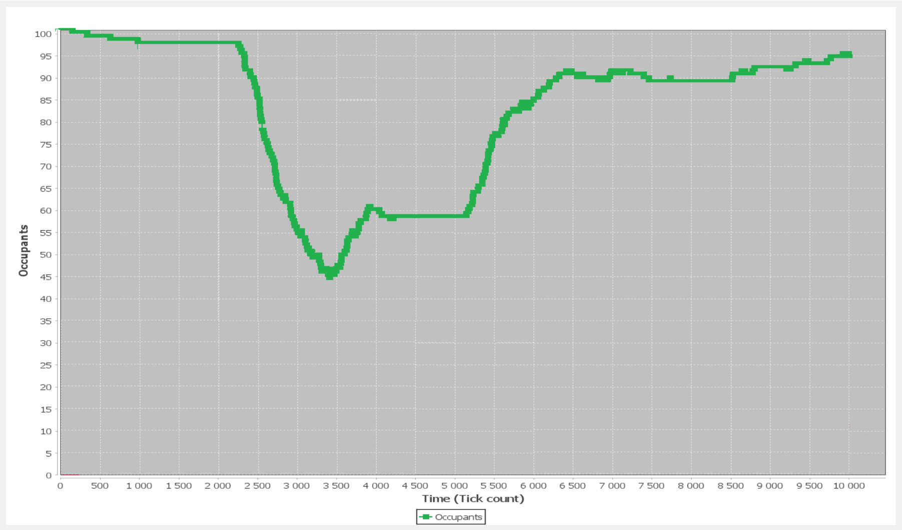

Figure 6.11: Experiment 2: The occupants of residential buildings

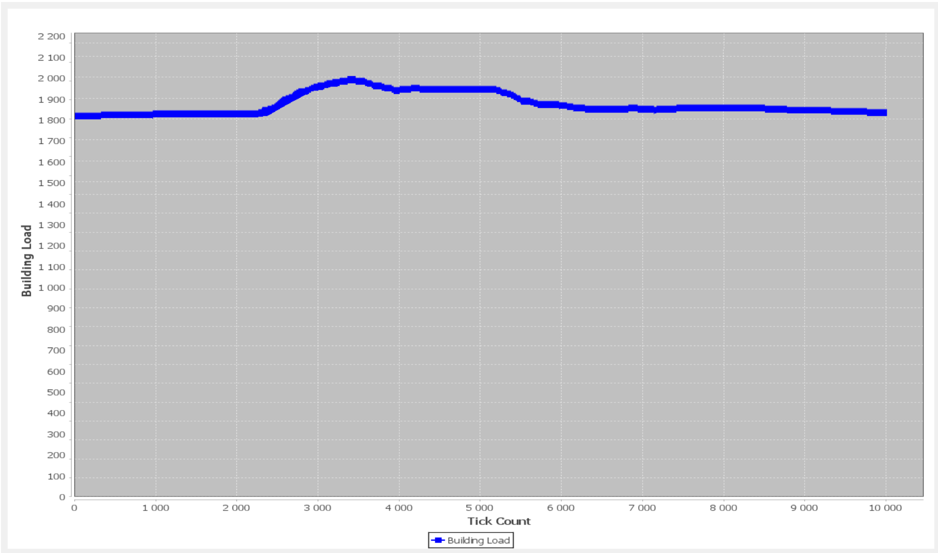

Figure 6.12: Experiment 2: Building load for industrial buildings

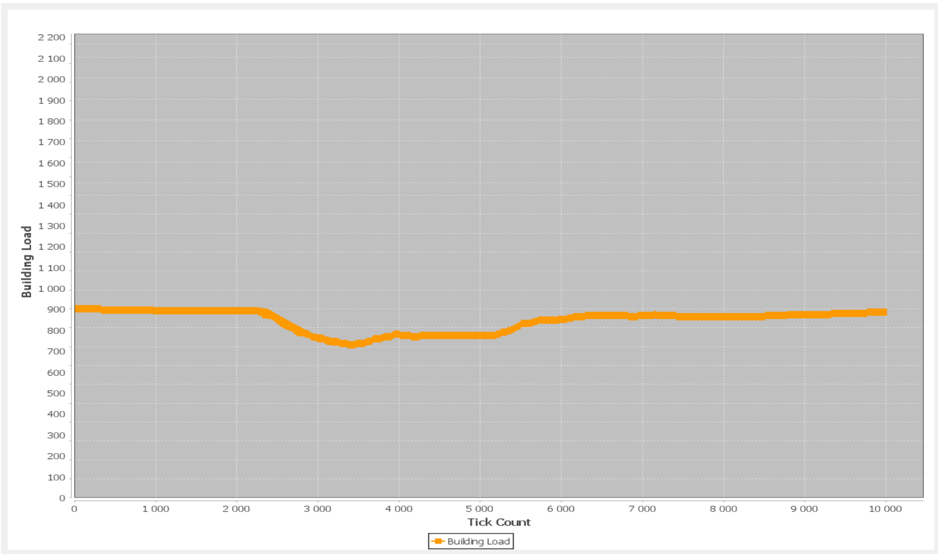

Figure 6.13: Experiment 2: Building load for residential buildings

The same type of dents observed in Experiment 1 can also be found here regarding the simulation's overall building load. Additionally, notice that there was a significant downfall in travel time. As half of the population does not travel, it results in less traffic for the other half that travels, resulting in significantly less time in traffic.

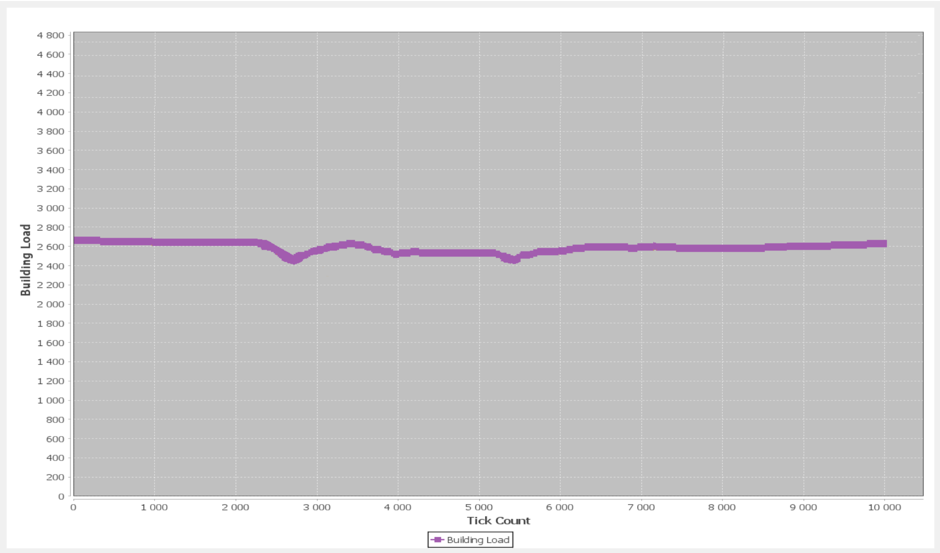

Figure 6.14: Experiment 2: Combined building loads

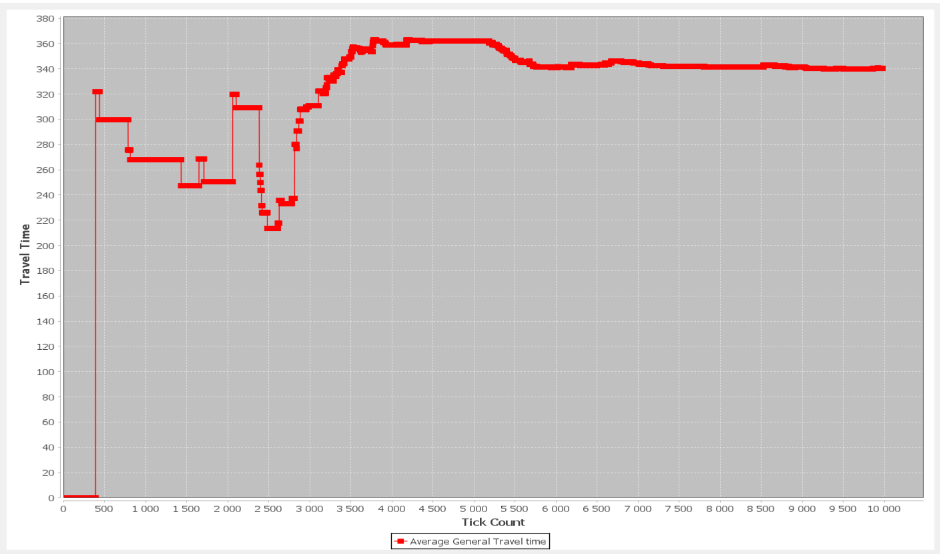

Figure 6.15: Experiment 2: Average general travel time

6.2.3 Experiment 3

The last demonstrated experiment simulated the situation where 75% of the population worked from home, while the last 25% traveled to their respective workplace and worked from there. The results of the simulation were as following:

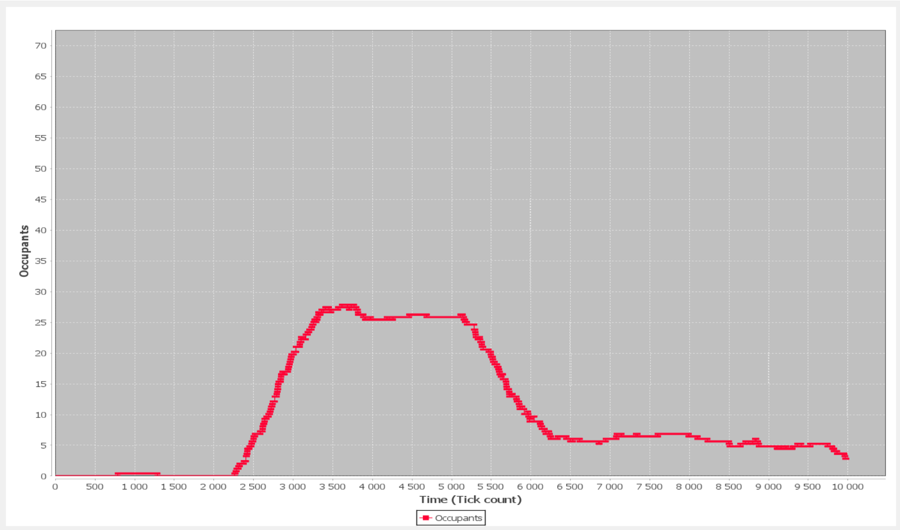

Figure 6.16: Experiment 3: The occupants of industrial buildings

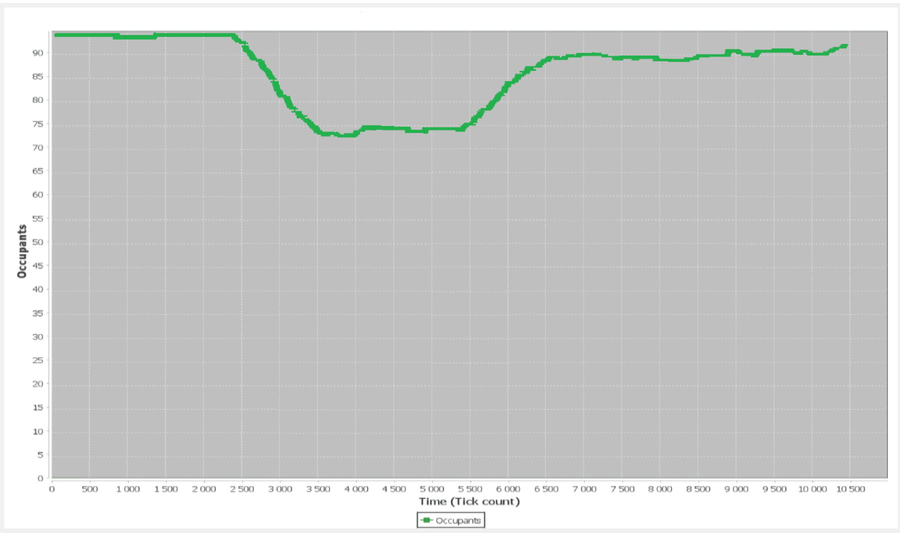

Figure 6.17: Experiment 3: The occupants of residential buildings

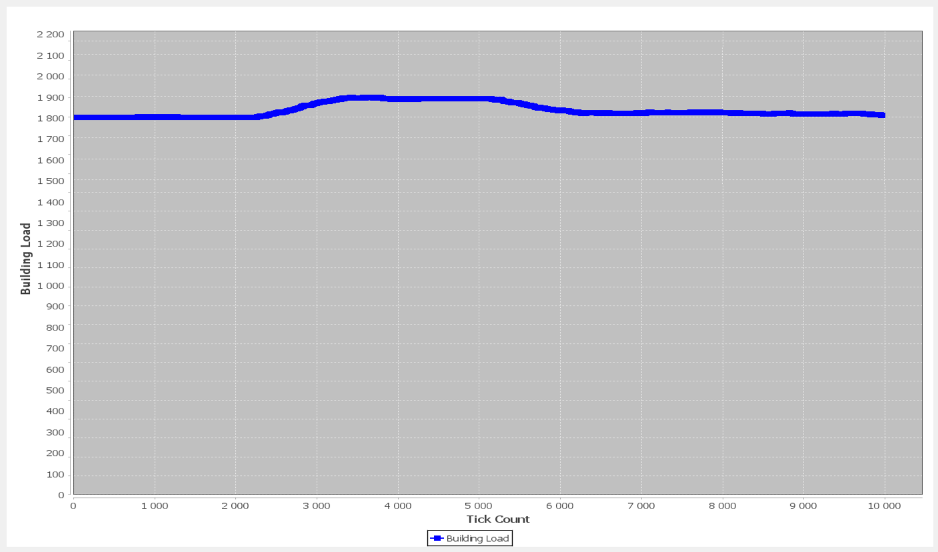

Figure 6.18: Experiment 3: Building load for industrial buildings

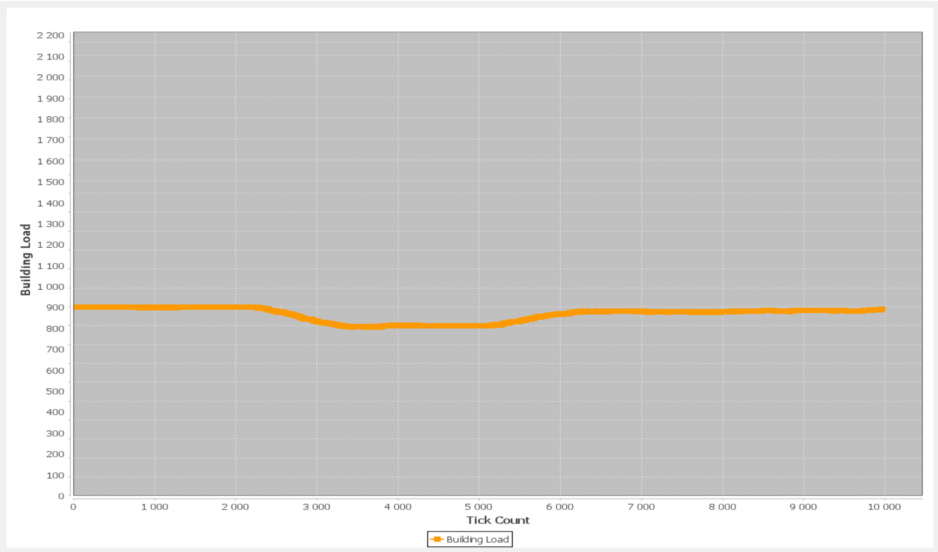

Figure 6.19: Experiment 3: Building load for residential buildings

Observe in Figure 6.20 that the similar types of dents observed in Experiment 1 and 2 still can be found in Experiment 3 regarding the simulation's overall building load, but notice that the dent is smaller than previously. The differentiation is mainly due to fewer agents moving around; thus, fewer agents move from one building to another, making the building load somewhat more stable.

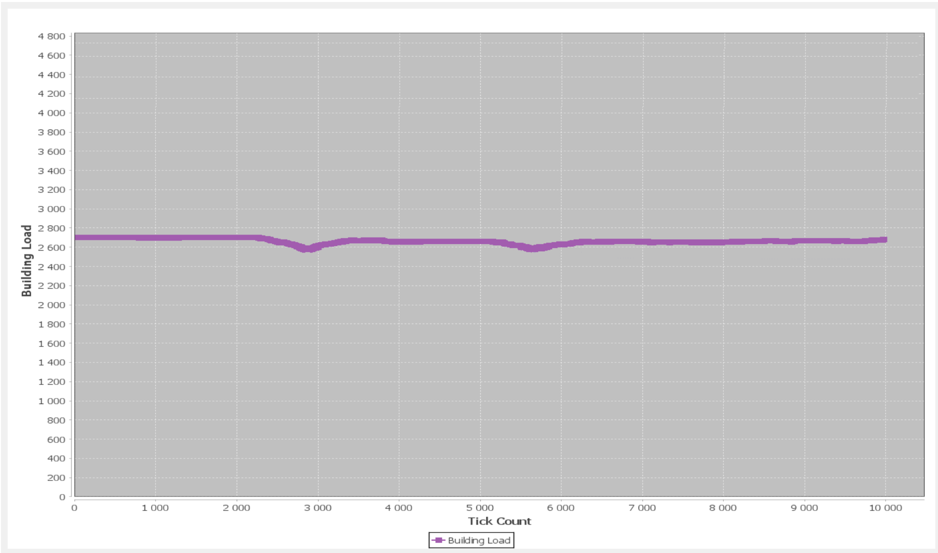

Figure 6.20: Experiment 3: Combined building loads

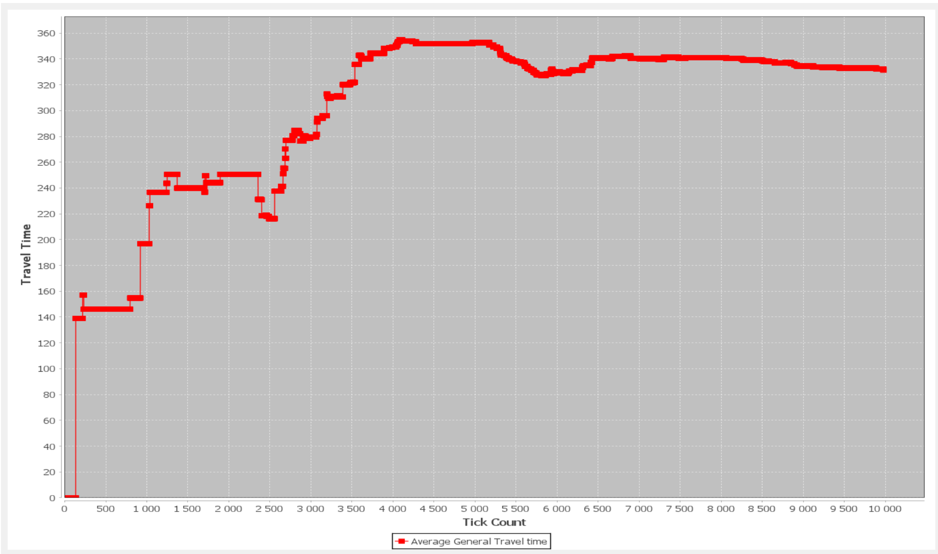

Figure 6.21: Experiment 3: Average general travel time

Additionally, in Figure 6.21 notice that there are minor changes to the travel time compared to the significant change in travel time between Experiment 1 and Experiment 2. Since the population reached a point where traffic could move fluidly without jam at a point between 100% population in the city and 50%, the travel time at some point converged, resulting in minor changes between Experiment 2 and 3.

Chapter 7

Evaluation

This chapter presents the aim of the evaluation, the conduction of the evaluation, and the evaluation results. Recall that research question 2 was about how the simulation model could benefit potential stakeholders. In order to answer RQ2, the user evaluation performed is critical to identify strengths and weaknesses with the project and identifying the value aspect of the project. The participants were chosen based on evaluation criteria elaborated on further into the chapter.

The evaluation mainly aims to answer RQ2 and its sub-research questions.

7.1 The evaluation process

The main outlines for the evaluation process consist of the initial identification of potential relevant stakeholders, contacting the relevant stakeholders. Then the evaluation itself was conducted as a semi-structured interview. After conducting the interviews, the work of processing and analyzing the data gathered were performed.

7.1.1 Identification of the participants

Identifying the potential relevant participants already started during pre-study, when focus talks and workshops gave an idea for which actors could be relevant stakeholders. After conducting the literature review, the stakeholder's relevance was further confirmed, where a potential application for such simulation concepts was discovered.

7.1.2 Participants

Chapter 3.4 briefly introduced the participants of the evaluation. This section will properly describe the participants of the evaluation.

The anticipated stakeholders consist of actors identified through a series of different events, some during the initial talks with Trondheim Municipality, others with the associate mentioned earlier from the architecture and urban design faculty. In addition, the literature review, to some extent, also provided a basis for relevant stakeholders. Given that city systems are established as complex systems, simulation concepts such as the one described in this thesis would provide an opportunity for stakeholders with occupations that work closely with urban development. The thesis assumed relatively early on in the project's lifetime that such a simulation would benefit this group, and the literature supports the interests (as described in 2.3.2, *An architectural approach to complex theory*). Finally, during the evaluation, several other potential stakeholders were identified as well.

The different participant groups consisted of:

- A professor in Urban Planning and Design, with over 25 years of experience
- Architects, including urban planning architects. Experience ranging from 1 to 10 years
- Urban Planners. Experience ranging from 1 to 15 years

The group of participants was chosen mainly based on their relevance to the field of urban planning and consists of a variety of different occupations within the field. The selection criteria for the participant required them to possess knowledge of urban planning and its implication, know about the city as a complex system, be aware of new trends within the field, and have experience with working on city systems. The participants were mainly contacted through an existing network of acquaintances, and others were individually contacted by e-mail. The initial contact e-mail can be found in Appendix B.

7.1.3 Conduction of the evaluation

Recall that chapter 3.2 described that the data generation method for the evaluation consists of a combination of a variant of interviews, questionnaires, and observations. The conduction of the evaluation session was performed as individual semi-structured interviews and can mainly be divided into four main parts; introduction, demonstration, topics to be discussed, and a questionnaire rating the system. After identifying, contacting, and agreeing upon a suitable time with the relevant stakeholders, an information sheet was sent out to the participants. The sheet informed them about their rights as a participant, what the data was to be used for, how the data would be stored, and what would happen to it after the project period. The information sheet is formed accordingly to NSD's guidelines, and NSD has approved it. The sheet can be found in Appendix A.

The interviews were held over Microsoft Teams, mainly due to the inability to meet the participant face to face. The reason was due to the restrictions around the pandemic. However, video meetings opened up for meeting different stakeholders located over a more significant geographical distance.

Introduction

The first part of the interview consists of a quick summary of the information sheet handed out to the participant beforehand before introducing the thesis with relevant information about the project, presenting the research questions, objectives, and aims. The participants were then informed about their role in the project and how the evaluation was to be conducted.

After the practicalities, the participants were asked to introduce themself with their name, occupational title, a summary of what tasks they did in their occupation field, and how many years of experience they had in their role. In short, the introduction of the participants aimed to get the following questions answered:

- Q1: What is your occupational title?
- Q2: What tasks do you perform in your role?
- Q3: How many years have you been working in this role?

These questions intend to confirm the participant's relevance with the initial contact established with them during the initial talks. Q1 and Q2 should be related to urban planning, and Q3 intends to explore how experience plays a role when evaluating areas of use.

Demonstration

The second part of the interview was the demonstration of the simulation. The demonstration consisted of a short explanation of the different concepts of the simulation, such as the different parameters, color codes, an outline of the agent's behavior, how the simulation built the physical environment, and more, before running the simulation. The simulation ran the experiment described in chapter 6. During the simulation, the different data produced while running was elaborated on, showing the different data graphs and the displayed graphical environment that the simulation ran in, illustrating the connected interaction of the agent's movement in the environment and the associated graphs visually. The simulation was run locally on a shared screen with shared control through Microsoft Teams. By doing this, the participant was able to refer to specific simulation elements where they had questions about the model. Furthermore, the participant was able to navigate around in the model while the simulation ran, examining different elements freely during the demonstration.

The reason for demonstrating the simulation this way instead of a traditional user-test where users usually are given tasks to perform was mainly due to the fact that the simulation at this stage is not a finished product suited to be evaluated in such a manner. The purpose of the evaluation is to identify the benefits of the simulation model regarding relevant stakeholders, not to evaluate the usability aspect.

Interview topics

The semi-structured interview consists of several topics to discuss, with a few specified questions within each category to help the conversation flow. The interview topics discussed the following:

- The value aspect
  - How can the demonstrated complex system model be advantageous within your field of work?
  - How do you imagine this can create value?
- Improvements
  - What do you think worked in such a simulation?

- What do you think did not work?
- What elements do you think needs to be included in order to make such a model better?

- Existing software
  - Do you know about similar kinds of simulation-model concepts?
  - How is it used in your field of work
  - What works/do not works with such concepts?
- Other factors
  - What do you think was the most valuable with such a concept?
  - What element in the concept do you think was the most important one?
  - Do you think the tool could be used to evaluate energy distribution from an urban planning perspective? If so, how?
  - Other factors to consider?

The topics discussed focus on answering how the simulation model can benefit the participant in the role of stakeholder and the benefits of such a model. Additionally, the topics wanted to identify what elements could be improved to increase the benefits of the model and whether the participant knew of existing simulation-model concepts that the thesis had overlooked when performing the research. Finally, as a sum-up question, the participant was directly asked if they thought whether or not the tool would evaluate the energy distribution from an urban perspective, and if so, how.

The last topic allows the participant to talk about other factors the concept might have overlooked, things they want to bring up, and straight-up ask what they think are the most valuable about the concept and what element they think is the most important. The answers will be summarized and discussed in chapter 7.2.

Questionnaire

The questionnaire can be found in the Appendix D. By the end of the interview, the participants were asked to complete a short questionnaire about their perception of the concept's usefulness and their perceived potential value of the concept. The questions used a Likert scale ranging from 0 - 10, with the additional option of "I do not know." Tabel 7.1 illustrates the scale.

D					N					A	IDK
0	1	2	3	4	5	6	7	8	9	10	?

Table 7.1: Likert scale. D = Disagree, N = Neutral, A = Agree, IDK = I don't know

While not being the most optimal practice, the questionnaire was taken in real-time, with the interviewer present. A strength of conducting it this way was that it offered the opportunity for the participant to resonate and argue for their answer and ask for clarification or discuss anything they would think of while filling out the questionnaire. A weakness would be that the participant could feel pressure and would give dishonest answers. However, given the option to argue for their choices to some degree neutralized this risk.

With some variation depending on the institution that describes the framework, the Technology Acceptance Model (TAM) [60] usually consists of the four aspects "Perceived usefulness," "Perceived ease-of-use," "Behavioral intention to use," and actual "Usage" [67]. The framework is mainly used to evaluate a user's intent to use a system or a finished product [68]. The questionnaire was made to give a quantification of the user's perception of the concept. Inspired by the perceived usefulness criteria of the TAM framework [69], the questionnaire aims to measure how useful the participants thought the simulation model would be as a decision support software in their field of work. In regards to the Perceived Usefulness criteria of TAM, there are four types of evaluation, which are: (1) increasing the effectiveness of work, (2) improve overall performance, (3) faster usage, and (4) menu usability [69]. The questionnaire in this thesis models after the first three criteria, asking questions concerning effectiveness, speed, and overall performance. The questionnaire excludes the fourth criteria, as the model is a software concept rather than a finalized program suited to be evaluated by the criteria of menu usability. Additionally, the questionnaire includes questions about the value aspect of the complex system model.

The questionnaire uses the proposed evaluation design for similar reasons to why not choosing to perform a fullfledged TAM or user-test of the concept; the simulation at this stage is not a finished product suited to be evaluated in such a manner. The simulation is, at this stage, a conceptual model showcasing the different functionalities and capabilities such a model is able to perform.

While TAM usually evaluates based on factors described above, this thesis will focus on collecting the participants' perception of usefulness based on the three factors effectiveness, performance, speed, and the overall value perception of the proposition. The following list presents the questions of the questionnaire.

- Q1. The interaction between the graphical simulation and the data is useful
- Q2. The simulation model concept will lead to more accurate decisions
- Q3. The simulation model concept will lead to faster decisions
- Q4. The simulation model concept will lead to more effective conduction of work tasks
- Q5. Overall, the simulation-model concept will lead to a better completion of the work tasks
- Q6. The purpose of such a concept is understandable
- Q7. I think the solution is a good idea
- Q8. I believe that the solution is advantageous to use within my field of work
- Q9. Previously, I have observed similar simulation-models or software
- Q10. I have a positive attitude towards such a solution
- Q11. I see a potential value of the concept

After the conduction of the evaluation was performed, the results were studied and analyzed. The following section will present the results of the evaluation.

7.2 Evaluation Results

As described in the evaluation process, the evaluation topics that were discussed with the participants were:

- Value focused
- Improvements
- Existing known software
- Miscellaneous

7.2.1 Value aspect

The questions asked within this topic were mainly *"How can the demonstrated complex system model be advantageous within your field?"*, followed up with a discussion for how the interview object imagine this could create value. The topic directly relates to answering RQ2 of how the complex system model can benefit the stakeholder.

The answers given had some variation across the different participants. The professor in urban planning stated that an area where such simulations would be outstanding would be regarding edge cases. Another participant, working as an urban planning architect, valued that such a tool could quantify elements that usually do not allow themselves to quantify that easily. This participant also mentioned how such simulations could "simulate how general rules could affect different capacity needs." Overall regarding this topic, the participants generally had a unified appreciation of the simulation model's ability to simulate changes of the minor component of the system, to witness changes in the larger picture.

One theme that occurred among the participants when discussing the value aspect was the topic of value in a sustainability context. Typically, to study changes in a city context, one either requires physically building the situation in real life, existing already built situations, or physically modeling the situation and performing "mind-simulations." "Mind-simulations" were explained by an architect working as an urban planner as building the context that was to be studied on a smaller scale (typically 1:1000, but could vary depending on the situation), and then discuss what would happen by introducing different layers of parameters on the model.

Additionally, for most architectural instances, each situation needs to be customized for its given context. By utilizing computer simulations, the need for building physical structures is reduced, thus providing value by saving time and resources, leading to a sustainable value of using such models. Another aspect would also be when introducing different parameters; thus, the model simulation would be more accessible and more accurately display these results. All participants also generally liked the opportunity to number-quantity elements that do not usually allow themselves to be quantified and mentioned that this was an obvious benefit.

As uncovered during the literature review, emergent behavior is tough to predict. Several urban planners shared this view that complexity is not necessarily possible to reflect upon, often rendering the "Mind-simulations" inaccurate. Thus through such simulations, a value would be provided when studying complex situations by simulating actual results instead of pure hypothesizes of what would happen.

7.2.2 Improvements

The improvement topic was discussed regarding what the participants thought was working in the simulations, what did not work, and what additional features would be needed to make the simulation model concept better.

Every participant involved mentioned that the interaction between the data provided and the displaying simulation with the agents moving around in the environment worked well. The participants pointed out that whenever a difference in the data graph would occur, this could be reflected by studying how the agents act in the simulation. One architect pointed out that in their field of work, graphical visuals are vital for their work in general, specifying that architecture and planning often involve aesthetics in addition to logistics.

None of the participants could think of anything in the existing model concerning what they did not think would work in the simulation. However, concerns about environmental variables such as social intellect and architectonic elements were brought up. Elements that agents do not necessarily represent due to aesthetic intellect. The architects and the urban planners with architect background brought up the importance of identifying pleasant urban spaces, which are not necessarily identifiable through such models, as pleasant urban spaces are often shared subjective opinions.

Another concern about such models that was brought up was the factor of scalability. While such models allow for grand scales, it is essential not to include too many variables—the bigger the simulation, the more elements to consider, thus more complex. Thus, a balance of scale and purpose is vital to identify before introducing too many elements.

Regarding elements to improve the simulation model, the participants answered quite differently. Some participants, usually with an architecture background, reflected upon the possibility of introducing several more architectural elements and social aspects. The others suggested a wider variety of elements to consider. For example, some elements suggested included a better distinction of transport agents, such as electric mobility solutions (scooters, bikes, and more), a wider variety of building types, including buildings with combined functions. An interesting suggestion brought up by the professor in urban planning was about implementing weighted parameters, giving the simulation a priority of results to consider.

During this part of the interview, it was mentioned that a city is more than the visible set of interactions and that including the different "invisible" interactions could enhance the model. Examples of "invisible" interactions include the paper stand interaction mentioned earlier described by Christopher Alexander in chapter 2.3.2, and an objective aesthetic rating of urban space described as "urban space that attracts inhabitants of the city to go there." The participant that stated about urban aesthetic rating elaborated with the following quote: "The amount of attractive green areas such as parks would definitely attract people to an area. It would be very fascinating to get some numbers on how greenery would affect citizens' motivation to stay in the city." Additionally, another participant with urban planning background suggested implementing the function of combining graphs in order to observe the overall outcome.

7.2.3 Existing known software

When discussing the topic of existing similar software or similar simulation or model tools, the participants were asked if they knew about similar tools within their field of work. The participants were then asked how the tools were utilized in their field of work. Lastly, the participants were asked to elaborate upon what works or does not work with such tools.

Surprisingly, none of the evaluation participants said they knew of any similar existing software, model, or simulation tools that would consider a city context as a complex system and simulate it through the different aspects with the diversity in parameters. The follow-up questions were then changed to ask how they usually got their data. Some mentioned logistics departments, while over half of all the participants mentioned historical data provided by Geographical Information Systems (GIS-tools). ArcGIS was the tool most frequently mentioned. The participants usually specified that GIS was used more as a tool for getting historical data rather than simulating data.

One honorable mention goes to a system designed by Telia named "City Vitality Insights" [70], mentioned by the city architect of Hamar municipality. The software uses a tracking system by the telecommunication company Telia, mainly used to understand the movement patterns of their users during Covid-19, based on phone traffic within a specific base station area. Hamar municipality utilized the framework for studying and understanding the context between population concentration, their movements, and the infection rate. The data studies the movement pattern within a given area based on how mobile phones move, and it then anonymized. However, similar to GIS, this is also based on existing historical data rather than generated data.

7.2.4 Miscellaneous

This topic was included as a summary point on whether or not the interview object had anything else they would want to bring up. The questions asked in this section were *"Other factors you want to touch on?"* Followed up by asking what they thought was the most valuable with the concept, and then, a question about what elements within the simulation concept they perceived as the most important one. Lastly, the participant was directly asked whether or not they thought the tool could be used to evaluate energy distribution from an urban planning perspective, and if so, how.

One topic that went by several times regarding the most important element of the simulation model was the visuals between the data generation and the simulation. All of the participants chose to highlight this interaction while they had already mentioned it during the value aspect topic, indicating their perception of it as very important in their field of work. It was stated that the graphical visuals were a deciding factor. *"To be able to see the unexpected"* indicates that the use of complex system simulation models to generate data within a complex adaptive environment provides value for urban planners.

When discussing the most valuable aspect of the concept, one participant with urban planning background highlighted that the simulation model would provide swift situation analysis by generating data. The participant further elaborated by discussing how the data could be utilized to study social sustainability and different settlement patterns: through generating data about a future state, for example, how cities can evolve and change due to choices urban planners make. The participant felt that flexibility in such cases could help for designing more pleasant and sustainable city spaces.

Interestingly enough, when discussing whether or not the participants had other factors they wanted to bring up, simulation games were brought up. One frequently mentioned game was a game called *"City Skyline"* [71]. The game, according to its host provider, is a modern take on the classic city simulation. The game introduces new gameplay elements to realize the thrill and hardships of creating and maintaining a city while expanding on established elements of the city. The player engages in urban planning by controlling zoning, road placement, taxation, public services, and public transportation. The player maintains various elements of the city, everything from budget to pollution levels. When asked about whether or not this could be used as a tool for their field of work or classify the game as an area of similar software concepts, the participants that brought it up stated that it could be classified as a similar simulation concept. However, they did not think of it as a tool as it was labeled as a game. Furthermore, the participants resonated that one of the most significant limitations of such a game is the level of simplicity and abstraction. The game is very limited in regards to what kind of parameters one can control. One of the participants quoted that:*"The game is not accurate enough to represent the reality"*. Additionally, the game at its current stage does not allow for retrieving data from it, making it unsuited as a tool.

Discussing whether or not the participants believed if the simulation model could be used as a tool to evaluate energy distribution from an urban planning perspective, the participants all agreed that it definitely could have its place in urban planning. None of the participants knew of tools that could evaluate the energy distribution in the demonstrated way. Several participants, usually with urban planning backgrounds, expressed a wish for such a tool as the simulation model to understand the energy distribution. Several participants also mentioned that historically, in situations where the demonstrated simulation model could be relevant, logistics engineers provided the data (usually historical data). The participants stated that they did not have a relation to it, nor did they know how the data came to be and potential sources of errors. Some quotes from the participants: "It would be nice with a simulation beside the data, such that you can "see" if something did not match in an overall graphical simulation." "A tool where you can potentially do an overall simulation for a comprehensive overview to get an idea of how the state of the situation is very nice. In conjunction with own decisions, of course." Regarding the how part, the participants were in unison that they believed the simulation model would mainly be a supplementary tool when evaluating a situation. "The tool should illustrate the situation and provide data, while actual people should make the decisions."

Lastly, a topic almost all of the participants emphasized was not relying too much and blindly on simulations. The participants argued that while simulations and models can provide excellent and accurate data, they should still be interpreted with a grain of salt. The results of such simulations should be considered in a specified defined context. The holistic picture is crucial when especially considering architectonic wholes, including aesthetic aspects.

7.2.5 The results of the questionnaire

Table 7.2 presents the results of the questionnaire. Note that the entry is removed from calculating the average score whenever the participant answered: "I don't know."

For the most part, Q1 (The interaction between the graphical simulation and the data is) overall held high regard. However, several participants, typically architects, were reluctant to give a ten due to the principle that "nothing can ever be perfect, and everything can be improved."

The participants generally did not resonate much around Q2 (The simulation model concept will lead to more accurate decisions) and overall agreed that the simulation model would lead to more accurate decisions. Q3 (The simulation-model concept will lead to faster decisions), on the other hand, created discussion and resonance, where the answers varied. Some participants reflected that it would lead to faster decisions in the holistic picture, as simulation models could create opportunities for action. Others argued that more data to process would lead to more time to analyze the results, thus overall a slower time to decide upon a decision. An interesting observation regarding Q3 was that, in general, the more experience the participant had, the more they thought the model would lead to faster decisions, thus tending to give a higher score. On the other hand, the less experienced participants (in relative terms of all the participants) gave lower scores on this question. The same applied to Q4 (The simulation-model concept will lead to more effective conduction of work tasks). The arguments that resonated about such a model would not necessarily lead to more effective conduction of the task, did so on the background of more data to analyze would lead to more factors to consider. However, the participants generally agreed that such simulation models would lead to higher quality in the decision-making, in the long run, thus being generally more effective. This reflection made the participants generally answer Q5 (Overall, the simulation-model concept will lead to a better completion of the work tasks) quickly, as the question was about the overall completion of tasks.

Regarding Q6 (The purpose of such a concept is understandable), when asked if the participant understood the concept, they all answered yes, but for some reason still did not choose to give it a 10. Q7 (I think the solution is a good idea), on the other hand, the majority agreed that such a solution is a good idea. One participant specified that it had to be under "the right given circumstances," while one architect mentioned: "especially for urban planners." Leading into Q8 (I believe that the solution is advantageous to use within my field of work), the participants believed that such simulation models, in general, are advantageous for them, of course, given the right circumstances and tailored to each unique situation.

For Q9 (Previously, I have observed similar simulation models or software), several participants who scored low explicitly defined that they had never seen such simulation models before tailored towards architectural purposes. Others said they had seen models before but could not remember the name and explicitly told that none of what they had seen before had the ability to simulate and generate data. The participants who had mentioned City Skyline earlier did not consider it a simulation model that they could use in their field of work, thus elaborating that they had not seen it being used within their profession.

For the two last questions, Q10 (I have a positive attitude towards such a solution) and Q11 (I see a potential value of the concept), the participants, for the most part, referred to the Miscellaneous part of the interview, generally rating the concept highly.

No.	Question	Lowest	Highest	Average	Mode
Q1	The interaction between the graphical simulation and the data is useful	8	10	8.7	9
Q2	The simulation-model concept will lead to more accurate decisions	7	9	8.3	8
Q3	The simulation-model concept will lead to faster decisions	6	9	7.6	7
Q4	The simulation-model concept will lead to more effective con-duction of work tasks	5	9	6.9	7
Q5	Overall, the simulation model concept will lead to a better completion of the work tasks	5	9	7.1	7
Q6	The purpose of such a concept is understandable	8	9	8.7	9
Q7	I think the solution is a good idea	8	10	8.9	9
Q8	I believe that the solution is adv-antageous to use within my field of work	7	10	8.3	8
Q9	Previously, I have observed similar simulation-models or software	1	3	2.1	2
Q10	I have a positive attitude towards such a solution	7	10	8.6	9
Q11	I see a potensial value of the concept	8	9	8.4	8

Table 7.2: The results of the questionnaire

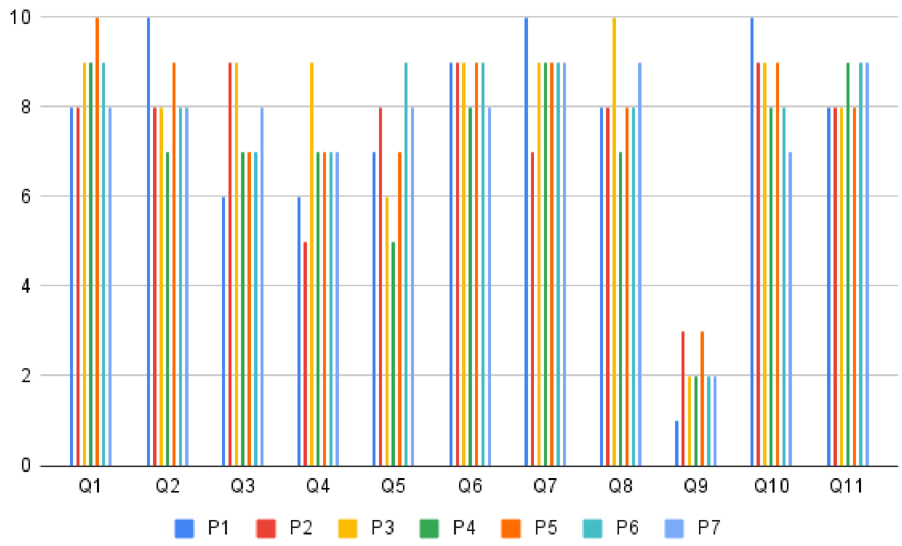

Figure 7.1: Graphical visualization of the results

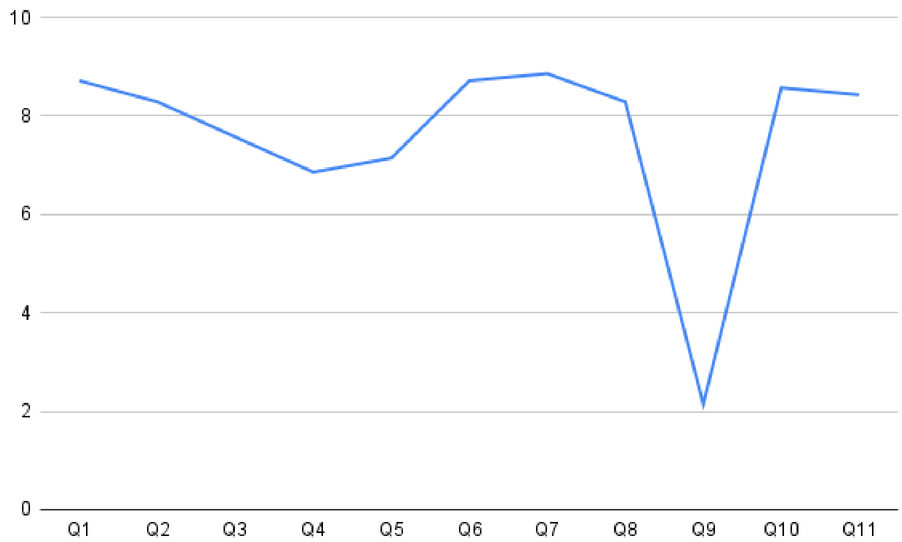

Figure 7.2: The average score for each question of the questionnaire

Chapter 8

Discussion

The previous chapters have taken a more in-depth look at the research results conducted in this project. Additionally, analysis and discussion of prior research and experiences have been conducted, presenting existing research and experiences identified in the literature study. This chapter will aim to answer the research questions presented in the first chapter.

8.1 The Research questions

Recall from the earlier chapters that the research questions for this thesis revolved around how complex system models can be utilized to understand energy distribution within an urban context and, more importantly, how the simulation model can be used to benefit stakeholders. The questions were mainly researched through a literature review, an implementation sprung from the literature review, and an evaluation of the simulation model concept as a whole. To decompose the project into smaller parts, sub-research questions were defined to help answer the main research questions. This section will attempt to discuss the research results in regards to the research questions and literature.

8.1.1 RQ1: How can complex system models be used as a tool to understand energy distribution within an urban context?

RQ1 was answered and illustrated through the literature and further demonstrated with the implementation through the experiments in chapter 6. In addition, the literature presented characteristics of complex systems and how complex system models can be adjusted to model. Complex system models can be used as a tool to understand energy distribution within an urban context by creating a simulation model consisting of the essential elements of the urban context, including the set of interactions between them as described in chapter 2.3. The simulation model needs to consist of an environment of the urban context, with elements such as buildings and road elements, similar to how chapter 5.2.2 the implementation of this thesis. In general, the environment needs to consist of sets of objects that agents can modify, as described in 2.2.2. The agents of the simulation model should operate in the environment, performing different actions. The model agents are autonomous and discrete units, capable of processing information and following a pre-defined ruleset. Chapter 5.2.3 describes the behavior of eCim's agents.

Summarized, the agents follow a set of traffic rules, sensing their environments and not colliding with each other. Each agent follows the rule of reaching their destination and consuming energy in the model, modifying the environment. Furthermore, the data that the agents and the environment generate need to be stored and presented visually to acquire an understanding of the energy distribution of the environment.

SRQ1.1: Why would such a case be suited to model as a complex system?

The literature study provided characteristics for a complex system as well as a complex adaptive system. The literature review discovers that a city indeed fits the definition of a complex system. It further compares city systems to the presented characteristics, discussing and elaborating why a city is a complex system. Chapter 2.3 provides in-depth why cities are complex systems. To summarize, city systems consist of various components ranging from industrial to social, each with its non-linear emergent behavior. Like the properties of a complex adaptive system, cities as an urban system have the ability to evolve, being a catalyst allowing for new behaviors to emerge, and have simple elements with simple rulesets that can result in broad complex outcomes. Cities are made with the human as a center, and there are many different actors that are autonomous and discrete units seen from a holistic perspective, each with their agenda. The findings indicate that the situation is suited to be modeled as a complex system utilizing agent-based modeling.

SRQ1.2: How can the complex system model illustrate how human movement and population distribution affect said energy distribution?

The model illustrates the situation by representing the system as a complex adaptive system utilizing an agent-based modeling approach; in this thesis' case as a multi-agent system within a complex adaptive system. The strengths of utilizing ABM lies in the direct mapping of each component of a complex system to be represented as individual entities in ABM, with the components being agents or a part of the environment. The agents and their behavior represent the population distribution and human movement patterns, affecting energy consumption by their innate energy consumption index. Wherever the higher concentration of agents in the model is, the energy distribution would be affected accordingly.

A pure simulation model itself would probably not be able to clearly illustrate how movement and population distribution can affect energy distribution. However, together with supplementary data graphs, it provides an accurate picture of how the the energy distribution is affected by the movement and the population distribution. In the implementation, graphs providing data are supplemented beside the display of the simulation model picture, fulfilling this need. Reflecting upon the results as of writing the thesis report, a better solution for showing the intersection of the data and display of the simulation could be to show the data graphs and the simulation model in the same picture through a hypothetical created dashboard. The dashboard could display the simulation model in motion, the belonging data graph, updated accordingly to the simulation models state, and numbers at a given time through a table, for example. Furthermore, as a participant suggested for improvements, a solid addition could be to add the possibility for combining graphs, showing different data combined with each other, to more easily see their connection. Additionally, the experiments demonstrated in chapter 6 provides examples of how the complex system model illustrates the situation.

8.1.2 RQ2: How could a complex system model of an urban context be beneficial for potential stakeholders?

RQ2 was mainly answered through a conducted expert evaluation with stakeholders. Overall, it was discovered that the simulation model could be beneficial in the stakeholders' work processes, especially when discussing hypothetical changes. In hindsight, the thesis could potentially have identified additional beneficial aspects if it had performed a survey or an outline of the stakeholders' work- and decision-making processes to better understand how the evaluated stakeholders work, with similarities to an enterprise model. The survey could have included modeling a process model, mapping out the different goals of the processes, surveying different concepts and terms, and so on. Regardless, the evaluation identified that the simulation model is beneficial by saving time, saving resources, being sustainable resulting from saving resources, and providing solid answers to situations that are yet to exist. An in-depth description of the benefits was uncovered in the evaluation results in chapter 7.2.

SRQ2.1: Whom would the stakeholders be?

During focus talks with actors relevant to the project, such as actors in the municipality and the consulted professor in architecture and urban design faculty, a potential group of stakeholders was identified. During these talks, the group consisting of architects and urban planners was deemed relevant because city planning and simulations with cities could relate to each other.

Later on, additional potential stakeholders were identified during the evaluation with the initial group of urban planners. The newly identified group consists of people or professions working with logistics and transport, such as logistic engineers. The new group of stakeholders was discovered as the initial group of urban planners frequently mentioned the new group when discussing existing software. It was usually this group of actors that provided them with data. The group of people working with logistics and data can be suited as they provide planners with relevant data and could have provided valuable insight to the evaluation through their point of view.

SRQ2.2: What are the benefits?

The benefits were mainly identified when evaluating the stakeholders. Several benefits consider sustainability aspects, including the ability to study change over time without the need to build the structure physically, saving time and resources, predicting unforeseen results of changes of a small scale. Additionally, the benefits of seeing the interaction between a visual simulation and graphical data make it easier to track why, as quoted by a planner: "strange, unexplainable event would occur" whenever an event like this appeared in the simulation. In short, clear benefits of the simulation model would be to save time by, to some degree, removing the need for studying real-life situations and getting an explanation for whenever strange events happen, resources, by removing the need to build real-life situations and physical models, and money through saving time and resources. Saving resources would also benefit the sustainability aspect within the field of urban planning.

A full elaboration of the benefits was previously presented in chapter 7.2 about the evaluation results.

8.2 Reflection

8.2.1 The Literature Review

As described in chapter 2.1, a variant of the structured literature review in computer science described by Kofod-Petersen was performed. One main argument to not follow the guideline strictly was due to the arguments of time constraint. However, in retrospect, the thesis could have gotten more value by methodically understanding the guideline provided by Kofod-Petersen earlier and followed it more strictly. The research could also have been expanded further with other resources, thus improving the quality, but the performed study was found adequate given the existing time constraint and available resources. Furthermore, since the sources are from acknowledged data science archives, and a background check was performed on each author (who they are, their educational background, publications, and credibility), the data gathered is deemed trustworthy.

8.2.2 Complex system modeling and ABM

The literature study identified a consistent framework fitting for modeling the case as a complex system, the agent-based model approach. More specifically, the subset of agent-based modeling; multi-agent modeling. The strengths of using agent-based modeling for complex system models mainly lie in the direct mapping of each component of a complex system to be represented as an individual entity in agent-based modeling, with components being agents or part of an environment. Multi-agent systems typically consider higher amounts of less intellectual agents, which the modeled situation better represents. As complex system theory deals with holistic systems consisting of many fundamental components to create a whole new system with emergent behavior, it is vital to decompose the parts to understand the system as a whole. The purpose of which agent-based modeling serves exceptionally.

8.2.3 Choice of environment

Recall that chapter 5 briefly discussed the reasons for creating new locations for the environment for the model simulations. The choice leads to the discussion of: would it have benefitted the thesis, both time and quality-wise, if the same area and environment from CitySim were used instead?

Implementing the changes upon CitySim's existing environment would most likely have saved time. However, the quality was likely to decrease as a result of it. During the initial focus talk with the associate from the architecture and planning faculty, emphasis was put on creating a relevant area since it was to be evaluated by experts that would consider the model from an architectural perspective. The associate elaborated that typically, such experts would be noticing aspects such as city entry points, structure densities, and generally, aesthetic and "non-technical" elements. The thesis could, in theory, had built a pure hypothetical area, increasing the intensity and activity of the area; however, it was concluded during the talks that this would probably not have the same impact as modeling an actual area. Modeling an actual area, or at least an area inspired by an actual one, would have the advantage of considering real-life situations that could have been overlooked when creating a hypothetical area, especially as the author of the thesis does not have a deep theoretical background in urban planning.

One evident limitation of the model's environment is the somewhat inaccurate representation of the building types. The initial area that the model built upon consists of buildings with a higher rating of combinations of residential and industrial. While the newly chosen area mainly consists of industrial buildings, combined industrial and residential buildings are excluded.

Another vital aspect of building an actual area was showing the participants that it is possible to adjust the model to represent a real-life situation and geographical area with moderate to low effort. By doing this, the benefit of creating a model in the given customized context was brought forth, which is crucial to be able to perform in their field of work.

8.2.4 Model Scalability

A crucial aspect brought up about the model and its environment, was the aspect of scalability. Recall in the evaluation results 7.2.2 that concerns about scalability were brought up. While complex system simulation models allow for grand scales, it is vital not to include too many variables nor consider a too great geographical area. The bigger the simulation, the more elements to consider, thus more complex. This concerns both the aspect of area size and variables. This view aligns with Priesmann et al.'s view for model simulation as reviewed in chapter 2.6. A more complex model formulation does not guarantee a more accurate result.

A simulation model with a higher degree of complexity would also require more computational time and resources to simulate. Thus it is critical to find the balancing line between too many and too few variables to make a complex system model.

8.2.5 Existing models/GIS

Observed in the evaluation, GIS was frequently mentioned when the participants were asked how their data was collected. Recall that when investigating modeling frameworks, the research article *"Complex adaptive system modeling with Repast Simphony"* [4] briefly mentioned that Repast Simphony provides some integration with a few GIS features. The features are referenced in a FAQ thread [72] that refers to the user manual [73] that further explains the usage of GIS features. Future work could include the enhancement of the model in regards to the integration of the GIS features.

Regarding City Vitality Insight, it might be worth checking out what the tool does explicitly, what the tool's properties are, or whether there are unseen opportunities that might help improve a simulation model. The author of the thesis has reached out to contact Telia to get more information about the tool but was told by Telia's customer support to contact the developers through a contact form E.1. However, Telia has not contacted back after submitting the form requesting more information about the tool as of the time of the dissemination of the thesis. Telia was contacted two weeks before the delivery date, right after City Vitality Insight was discovered in an evaluation. The form for requesting more information can be found here: https://www.telia.no/bedrift/digitalisering/crowd-insights/city-vitality-insights/.

Other things that could be considered to explore at a later point would be a review of the previously mentioned game "City Skyline." From briefly looking at its gameplay through reviews and playthroughs, the game might have the potential to behave like a simulation. Due to the time of discovery of the game, a proper evaluation of it has not been done. For eventual further work would be to explore what kind of data it can provide, the opportunities to extract and present said data, and what kind of integration it has. Regardless, it can serve as an inspiration for generating ideas for how simulation tools can create value.

8.2.6 The Evaluation Method

Recall from chapter 3.2 that the evaluation method was a method for gathering data and consisted of a combination of different data generation methods as described in *Researching Information Systems and Computing* [3]. The reason for choosing this combination was that it was deemed fit to fulfill Goal C, identify needs and specific valuable aspects of a model, and evaluate with stakeholders. It was decided relatively early on that it was essential to be able to have one on one contact with the evaluatee in order to observe their reactions and to adapt the questions of the semi-structured interview for it to get the desired answers.

A customized framework that adapted the perceived usefulness criteria from the Technology Acceptance Model was used regarding the evaluation questionnaire. The reason for not using the whole TAM framework is because it is better suited to be used on a finished product, evaluating perceived usefulness, perceived ease of use, the attitude of using, the intent of use, and actual usage. As the simulation model developed in this thesis is a conceptual model, more similar to a prototype rather than a finished product, it should not be evaluated as one. The argument is the same for why the concept is not user-tested or evaluated with regards to usability; the prototype is not user-friendly, it does not have a proper graphical user interface, and it is mainly only operatable by people with knowledge in coding. Recall that chapter 7.1.3 also provided an explanation for the choice,

8.2.7 Participants of the Evaluation

An interesting observation about the evaluation's participants is regarding their answers, considering what role and how much experience they had. Overall, the group was relatively homogeneous, consisting of urban planners and architects that worked as urban planners. The exception was the architects and the professor in urban planning and design. Overall during the interviews, the participants with an architectural background tended to consider more aesthetic aspects, providing perspective on environmental and social variables. On the other hand, the pure urban planners tended to consider more practical aspects, often looking for a straightforward solution to a problem.

Considering the topics about tasks, processes, and effectiveness, the more work experience the participant had, the more confidence they had in their answers. Conversely, the less experience the participants had, the more reflective they were on the topics and considering more pros and cons about effectiveness. The prime example would be regarding the question about whether or not the demonstrated simulation model would lead to more effective completion of work tasks. The less experienced participants resonated that the more data to process, the more time it would take, thus leading to less effective conduction of tasks. On the other hand, the experienced participants more or less instantly answered that the simulation model would lead to more effective and better quality task completion. Furthermore, the experienced participants stated that in the long run, the time to process the extra data would mean nothing compared to a less optimal or bad decision needing to be done over.

Chapter 9

Conclusion and Future Work

This thesis set out to identify the applications and benefits of complex system modeling by simulating an urban context. It started with a literature study researching topics related to modeling approaches, how an urban context compares to a complex system, and the data basis for building a complex system model embracing an urban system. It then modifies an existing model framework to fit the purpose of presenting experiments that affect an urban system, utilizing topics from the literature review such as complex system theory and agent-based modeling. The model proposed aims to illustrate how a newly introduced regulation could affect an urban complex system. Thus, three experiments were defined and performed to demonstrate how the simulation model can be used. Furthermore, the thesis explored how a group of identified stakeholders could utilize the model within their field of work, identifying the benefits of a complex system model. The identified stakeholders consist of urban planners and architects working with urban planning.

The goals of the thesis were to: (Goal A) achieve an overview of complex system model theory and agent-based model theory to be able to model a city, (Goal B) define a conceptual model for simulating and analyzing the activities of the urban context, and(Goal C) identify the needs and valuable aspects of the defined simulation model based on feedback from stakeholders. The goals were defined as criteria to support answering the research questions, discussed in chapter 8. Goal A, connected to RQ1, was achieved through the literature, identifying complex system- and agent-based modeling characteristics and then setting them in the context of the city. Goal B, connected to RQ1 and SRQ1.2, was achieved through the literature, the implementation, and the results. The thesis achieved the goal by utilizing the literature to define a conceptual framework, using the framework to analyze and demonstrate the changes and activities, and studying the results to observe how the environment was affected. Goal C, connected to RQ2, was achieved by evaluating the simulation model with identified stakeholders regarding the value aspect and how the model could be beneficial.

The goals of the thesis were never to create a model that would consider every detail or parameter of the complex city system but rather identify and create a usable situation that identified relevant stakeholders could evaluate. In short, eCim modified an existing model framework to fit its purposes and then used it to evaluate the benefits of using the simulation model within the profession-field of relevant stakeholders.

When reflecting upon the work performed, the thesis could probably have achieved more by following the strict guidelines of a structured literature review. In retrospect, by following the stricter method of structured literature review, it would probably have been easier to scope and define the thesis project. Regarding the evaluations, the sessions could have increased in quality if a survey of the evaluation participants' work processes had been mapped out beforehand. Unfortunately, the thesis' author did not think of utilizing process modeling until after the last interview. By this point, it was too late to incorporate due to time restrictions. Another topic to reflect upon is the implementation strategy. While utilizing an iterative and incremental development strategy to develop an existing framework further probably saved a significant amount of time, much time was utilized to reverse engineer portions of the existing code and coordinating code reviews with the founder of the existing code. However, knowing the author, had the thesis developed a framework from scratch, the regret would probably have been whether it had been better to iteratively and incrementally develop an existing framework further.

The thesis work performed has provided a tremendous amount of experience in performing scientific research, especially regarding the topics of studying existing work with methods like a literature study. As mentioned in the previous paragraph, an adequately structured literature review would be preferred in hypothetical future research. In addition, it was a great experience to utilize existing competence when performing the thesis work, such as development strategies, different research methods, and in general, existing knowledge from past years with computer science, as well as existing knowledge from past studies. Thus, for whatever future research that the author of this thesis will conduct, the experiences from this thesis will be applicable and helpful.

Regardless, future work rooted in this thesis could include:

Explore the possibility of GIS integration

As discovered in chapter 4.1, Repast Simphony provides integration with GIS. Since the topic of GIS was frequently mentioned during the evaluation, it might be interesting to check out the capabilities of GIS in conjunction with the Repast Simphony framework.

Study of City Vitality Insight

City Vitality Insights was, as previously mentioned, used by Hamar municipality during the height of the pandemic to survey the movement patterns of the population. A study of what the system is and how it can be used might prove helpful for further improvements of the simulation model that this thesis has developed.

Analysis of the stakeholders internal work processes

Reflecting upon the work performed, the thesis could possibly have gotten more out of the research if the work processes of the stakeholders evaluated were mapped out at a workshop or a separate interview beforehand. For future work, the author of the thesis recommends that process modeling of the relevant stakeholders' work processes is performed to understand better how the stakeholders perform their work. While urban planners have vastly different methods for work depending on each municipality or office, a process model could at least map out standard processes that they use. Such results could lead to a better, shared understanding of the different terminologies of the different parties and lead to a clearer understanding of each other. Suppose the result does not lead to this outcome. In that case, a process model could still serve as a common ground and a visual aid when discussing or evaluating with the relevant stakeholders.

Defining functional requirements

Further work could include defining functional requirements and implementing the requirements for the simulation model, targeting the identified stakeholder group of urban planners to customize the simulation model's applications.

Other relevant actors

During the evaluation, other potential stakeholders for the model simulation were uncovered. This group includes logistic engineers, traffic engineers, and in general, people working with logistics and data gathering in cities. The group was introduced individually by several evaluation participants as the actor that usually provided the urban planners with data. How this stakeholder group acquires their data, their work processes, and whether or not the simulation model could benefit this stakeholder group could be interesting to research.

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Appendices

Appendix A

Informasjonsskriv: Vil du delta i forskningsprosjektet eCim?

Dette er et spørsmål til deg om å delta i et forskningsprosjekt hvor formålet er å evaluere en prototype av data simulering. I dette skrivet gir vi deg informasjon om målene for prosjektet og hva deltakelse vil innebære for deg.

Formål

Prosjektets formål går ut på å utforske hvordan komplekst system teori kan anvendes til å forstå energi- forbruk og fordeling gitt en urban kontekst. For å kartlegge bruks- og nytteverdien av prosjektet, er det nødvendig å gjennomføre en evaluering av data-simuleringen.

Hvem er ansvarlig for forskningsprosjektet?

Norges teknisk-naturvitenskapelige universitet / Fakultet for informasjonsteknologi og elektroteknikk (IE) / Institutt for datateknologi og informatikk er ansvarlig for prosjektet.

Hvorfor får du spørsmål om å delta?

Du er valgt ut til å delta basert på din kompetansebakgrunn og ansees som en potensiell sluttbruker av prototypens sluttprodukt.

Hva innebærer det for deg å delta?

For deg som deltager, innebærer dette å delta på et semi-strukturert intervju, hvor temaer relatert til bruksverdi kommer til å være sentralt. Videre vil tanker du som deltager ha for å forbedre prototypen belyses. Personlige opplysninger som samles inn er navn, kompetansebakgrunn og yrke.

- Hvis du velger å delta i prosjektet, innebærer det også at du fyller ut et kort spørreskjema. Dette vil ta mellom 5-10 minutter. Spørreskjemaet vil inkludere spørsmål om hvor brukbart du som deltager anser datasimuleringen, mulige bruksscenarioer, samt brukbarhet av resultatet. Dine svar fra spørreskjemaet vil bli registrert elektronisk

Det er frivillig å delta

Det er frivillig å delta i prosjektet. Hvis du velger å delta, kan du når som helst trekke samtykket tilbake uten å oppgi noen grunn. Alle dine personopplysninger vil da bli slettet. Det vil ikke ha noen negative konsekvenser for deg hvis du ikke vil delta eller senere velger å trekke deg.

Personvern

Ditt personvern – hvordan vi oppbevarer og bruker dine opplysninger

Vi vil bare bruke opplysningene om deg til formålene vi har fortalt om i dette skrivet. Vi behandler opplysningene konfidensielt og i samsvar med personvernregelverket. Behandlingsansvarlig vil ligge på studenten som har ansvaret for masteroppgaven. Tiltak som gjennomføres for å sikre personopplysninger er adgangsbegrensning, endringslogg samt flerfaktorautentisering.

Hva skjer med opplysningene dine når vi avslutter forskningsprosjektet?

Opplysningene anonymiseres når prosjektet avsluttes/oppgaven er godkjent, noe som etter planen er 15. Juni 2021. Personopplysningene og eventuelle opptak slettes ved prosjektslutt

Hva gir oss rett til å behandle personopplysninger om deg?

Vi behandler opplysninger om deg basert på ditt samtykke.

På oppdrag fra Norges teknisk-naturvitenskapelige universitet / Fakultet for informasjonsteknologi og elektroteknikk (IE) / Institutt for datateknologi og informatikk har NSD – Norsk senter for forskningsdata AS vurdert at behandlingen av personopplysninger i dette prosjektet er i samsvar med personvernregelverket.

Dine rettigheter

Så lenge du kan identifiseres i datamaterialet, har du rett til:

- Innsyn i hvilke opplysninger vi behandler om deg, og å få utlevert en kopi av opplysningene
- Å få rettet opplysninger om deg som er feil eller misvisende
- Å få slettet personopplysninger om deg
- Å sende klage til Datatilsynet om behandlingen av dine personopplysninger

Hvis du har spørsmål til studien, eller ønsker å vite mer om eller benytte deg av dine rettigheter, ta kontakt med:

- Norges teknisk-naturvitenskapelige universitet / Fakultet for informasjonsteknologi og elektroteknikk (IE) / Institutt for datateknologi og informatikk ved Dennis Jianbin Liang og Sobah Abbas Petersen.
- Vårt personvernombud: Norges teknisk-naturvitenskapelige universitet / Fakultet for informasjonsteknologi og elektroteknikk (IE) / Institutt for datateknologi og informatikk, ved Thron Aass (thron.aass@ntnu.no / tel: 73412894 / +4745437065)

Hvis du har spørsmål knyttet til NSD sin vurdering av prosjektet, kan du ta kontakt med:

- NSD – Norsk senter for forskningsdata AS på epost (personverntjenester@nsd.no) eller på telefon: 55 58 21 17.

Med vennlig hilsen:

Sobah Abbas Peters Dennis Jianbin Liang

(Forsker/veileder)

Samtykkeerklæring

Jeg har mottatt og forstått informasjon om prosjektet eCim, og har fått anledning til å stille spørsmål. Jeg samtykker til:

- å delta i evalueringen av simuleringen

Jeg samtykker til at mine opplysninger behandles frem til prosjektet er avsluttet

(Signert av prosjektdeltaker, dato)

Appendix B

Initial request for participation in evaluation

Deltagelse i konseptevaluering i forbindelse masteroppgave våren 2021 ved NTNU

Dennis Jianbin Liang

til [redacted]

God ettermiddag.

Mitt navn er Dennis, og jeg skriver for tiden en masteroppgave om datasimulering av komplekse systemer innenfor en urban kontekst ved NTNU. I den sammenheng ønsker jeg tilbakemeldinger og evaluering av en prototype på en slik simuleringsmodell.

Kunne du, som person med arkitekt/byplanleggingsbakgrunn, tenke deg i å delta i en evaluering av et slikt konsept? Evalueringen kommer til å foregå som et intervju, som varer i ca. 30 minutter til en time, og kan legges fleksibelt til når du er tilgjengelig.

Hadde satt utrolig stor pris på om du tok deg tiden til dette.

--

mvh. Dennis Jianbin Liang

Figure B.1: Initial request asking participants if they were interested in participating in the evaluation of the simulation model

Appendix C

Interview-template

Intervjutemplate
Navn og rolle:
Dato:

Praktisk informasjon og avklaringer

- Oppsummere infoskriv
- Avklare anonymitet/åpenhet
- Informere intervjuobjektet at det vil bli tilsendt transkribert versjon i etterkant av intervjuet.
- Informere om bruk av lydopptak

Kandidatpresentasjon

- Kandidat for mulighet til å presentere seg selv og sin erfaring. Navn, yrkesrolle, arbeidserfaring.

Introduksjon

- Introduser prosjektet

- Relevant infor om prosjektet
- Presenter forskningsspørsmål og mål
- Informer om deltagerens rolle i prosessen

Introduksjon og bakgrunn for gjennomført arbeid presenteres. Sentrale begrep som komplekse systemer og emergence oppførsel forklares. En demostrasjon av datasimuleringen gjennomføres.

Hovedformålene til denne masteroppgaven er å undersøke hvordan komplekse system modeller kan brukes som et verktøy for å forstå energifordeling i en urban kontekst, og hvordan en slik simulering kan ha nytteverdi for ditt kompetanseområde med relasjoner til byutvikling og planlegging. Et komplekst adaptiv system er et system som består av flere mindre og ofte "enkle" systemer som sammen danner et system med en "emergent" oppførsel. "Emergent behavior" er et viktig nøkkelkonsept i denne sammenhengen, og kan vel oversettes til noe lignende av at det oppstår en uventet oppførsel. Fokuset med slike studier er å forsøke å simulere uforusett oppførsel fra det helhetlige systemet.

- Gi et lite pusterom og spør deltageren om dette var forståelig
- Legg gjerne ved analogien om maur-koloni

Holde en kontinuerlig interaksjon med deltageren. Viktig å ikke miste dem allerede i dette stadiet.

Som et verktøy for å studere slike tilfeller, brukes ofte datasimuleringer, eller datamodeller, hvor man programmerer oppførselen til de små eller enkle komponentene, og setter dem i en kontekst, et "environment" eller miljø, for så å studere oppførselen til den helhetlige konteksten.

I kontekst av denne oppgaven er agentene biler og mennesker styrt av mål menneskene har, og miljøet dette er plassert i er Trondheim sentrum samt et tilhørende boligområde. En eksempelsituasjon for en simulering kan være økende bruk av hjemmekontor, hvor simuleringen deler opp i flere ulike situasjoner hvor en andel av befolkningen er påkrevd hjemmekontor.

Demonstrer simuleringen.

Demo av simulering:

- Vise Display av simulering (husk å zoome inn i delene for å se hvordan ting ser ut)
- Forklare de forskjellige parameterene , fargekoder, agentene, det fysiske miljøet osv.
- Vise grafene, og forklare hva aksene representerer

Temaer som ønskes belyst

1. Hvordan kan en slik data-simulering være fordelsaktig innen ditt felt
   (a) Hvordan ser du for deg at dette kan skape verdi
2. Forbedringer
   (a) Hvilke elementer mener du trenges eller ser du for deg kunne være et godt tilskudd for å gjøre en slik programvare nyttig
3. Eksisterende programvare
   (a) Hvilke lignende type programvare med tilsvarende konsepter vet du om?
   (b) Hva slags bruksområde har disse for ditt arbeidsområde
   (c) Hva fungerer/ikke fungerer med slik programvare
4. Andre faktorer
   (a) Andre faktorer å ta hensyn til?
   (b) Hva synes du var mest verdifult med konseptet?
   (c) Tror du verktøyet kan brukes til å evaluere energifordelingen fra et byplanleggingsperspektiv? Hvis ja, hvordan?
   (d) Hvilke elementer i konseptet synes du var det viktigste?

Spørreundersøkelsen

Informere om spørreundersøkelsen og om rammeverket denne er inspirert av. *"Vi kommer å evaluere med et rammeverk som er inspirert av den opplevde nytteverdi-aspektet av TAM; Technology acceptance Model, for å vurdere hvor brukbart du tror et slik konsept vil være."*

Q1. Samspillet mellom den grafiske simuleringen og dataen er nyttig
Q2. Modellsimulerings-konseptet vil føre til mer nøyaktige beslutninger
Q3. Modellsimulerings-konseptet vil føre til raskere beslutninger
Q4. Modellsimulerings-konseptet vil føre til mer effektiv gjennomføring av arbeidsoppgaver
Q5. Helhetlig, vil modellsimulerings-konseptet føre til raskere fullføring av arbeidsoppgaver
Q6. Formålet med modellsimulerings-konseptet er forståelig
Q7. Jeg tror løsninger er en god ide
Q8. Jeg tror løsninger kan være fordelsaktig å bruke for dette fagfeltet
Q9. Jeg har observert lignende programvare tidligere
Q10. Jeg har et positivt inntrykk av løsningen
Q11. Jeg ser en potensiell verdi av konseptet

Appendix D

Questionnaire

Q1. Samspillet mellom den grafiske simuleringen og dataen er nyttig

D					N					A	IDK
0	1	2	3	4	5	6	7	8	9	10	?

D = Disagree, N = Neutral, A = Agree, IDK = I don't know

Q2. Modellsimulerings-konseptet vil føre til mer nøyaktige beslutninger

D					N					A	IDK
0	1	2	3	4	5	6	7	8	9	10	?

D = Disagree, N = Neutral, A = Agree, IDK = I don't know

Q3. Modellsimulerings-konseptet vil føre til raskere beslutninger

D					N					A	IDK
0	1	2	3	4	5	6	7	8	9	10	?

D = Disagree, N = Neutral, A = Agree, IDK = I don't know

Q4. Modellsimulerings-konseptet vil føre til mer effektiv gjennomføring av arbeidsoppgaver

D					N					A	IDK
0	1	2	3	4	5	6	7	8	9	10	?

D = Disagree, N = Neutral, A = Agree, IDK = I don't know

Q5. Helhetlig, vil modellsimulerings-konseptet føre til bedre gjennomføring av arbeidsoppgaver

D					N					A	IDK
0	1	2	3	4	5	6	7	8	9	10	?

D = Disagree, N = Neutral, A = Agree, IDK = I don't know

Q6. Formålet med modellsimulerings-konseptet er forståelig

D					N					A	IDK
0	1	2	3	4	5	6	7	8	9	10	?

D = Disagree, N = Neutral, A = Agree, IDK = I don't know

Q7. Jeg tror løsninger er en god ide

D					N					A	IDK
0	1	2	3	4	5	6	7	8	9	10	?

D = Disagree, N = Neutral, A = Agree, IDK = I don't know

Q8. Jeg tror løsninger kan være fordelsaktig å bruke for dette fagfeltet

D					N					A	IDK
0	1	2	3	4	5	6	7	8	9	10	?

D = Disagree, N = Neutral, A = Agree, IDK = I don't know

Q9. Jeg har observert lignende modellsimuleringer eller programvare tidligere

D					N					A	IDK
0	1	2	3	4	5	6	7	8	9	10	?

D = Disagree, N = Neutral, A = Agree, IDK = I don't know

Q10. Jeg har et positivt inntrykk av løsningen

D					N					A	IDK
0	1	2	3	4	5	6	7	8	9	10	?

D = Disagree, N = Neutral, A = Agree, IDK = I don't know

Q11. Jeg ser en potensiell verdi av konseptet

D					N					A	IDK
0	1	2	3	4	5	6	7	8	9	10	?

D = Disagree, N = Neutral, A = Agree, IDK = I don’t know

Appendix E

Contact with Telia's customer support

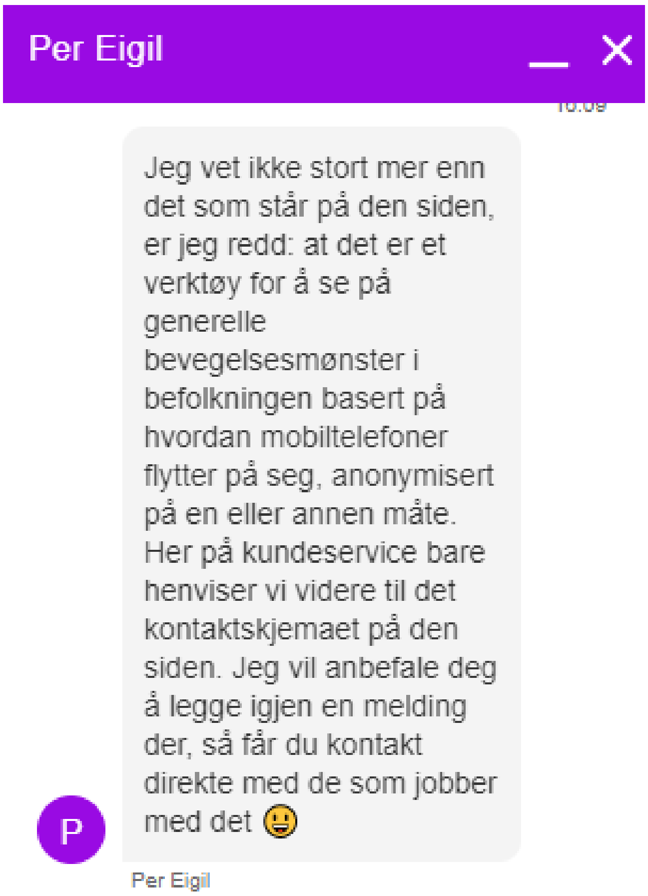

Figure E.1: Answer from Telia's customer support when contacting about City Vitality Insights

Dennis Jianbin Liang

eCim - An evaluation of a complex system model

NTNU
Norwegian University of
Science and Technology